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28 JUNE 1971

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STUDY OF ALTERNATE SPACE SHUTTLE CONCEPTS

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TASK IV FINAL REPORT

Prepared for George C. Marshall Space Flight Center by
Manned Space Programs, Space Systems Division

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

MSFC-DRL No. 216
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FOREWORD

The Study of Alternate Space Shuttle Concepts (ACS) (Phase A) was conducted by the Lockheed Missiles & Space Company for the Marshall Spacecraft Center under Contract NAS 8-26362, and a final report (LMSC-A989142) was delivered on 4 June 1971. A separate task (Task IV of ACS) was initiated on 1 April 1971 and scheduled for completion on 30 June 1971. The study results of this task are reported in this volume; Engineering Memorandums (EMs) that describe supporting analysis are referenced throughout the text and contained in the appendix to the report, published as a separate volume.

Reference is made to the following reports which have been submitted as required by the contract and are on file in the MSFC Documentation Repository H and TS-MS-D.

Subject	LMSC No.	Date
Study Plan Task IV	A987267	5 May 1971
Alternate Concepts Status Review (First Status Review Task IV)	A990507	29 Apr 1971
Second Status Review Task IV	ACS-132	3 Jun 1971
ACS – Study Task IV, Minutes of Second Status Review	A990569	8 Jun 1971

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Lockheed
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In Reply Refer To:
IMSC-A992533
Orgn. 67-20, B/562

July 6, 1971

Mr. W. A. Lenoir (A&TS-PR-RP-F)
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Subject: Contract NAS8-26362
Addendum No. 1 to Final Report

Reference: (A) Lockheed Report IMSC-A989142, dated 2 June 1971

Enclosure: (1) One (1) copy of Task IV Final Report, IMSC-A990949
(2) Distribution List

Dear Mr. Lenoir:

The enclosed Addendum No. 1 to the Alternate Space Shuttle Concept Study Final Report of Reference (A) is submitted in accordance with Appendix "E", Section 3, Data Requirements and the requirements of Item 7 as added by Supplemental Agreement No. 5 to the subject contract. Supplemental distribution indicated below and as set forth in Enclosure (2) has also been effected.

LOCKHEED MISSILES & SPACE COMPANY
SPACE SYSTEMS DIVISION

R. Noel Mendoza

R. Noel Mendoza
Chief Contract Administrator
Manned Space Programs

RNM:Jo

cc: NASA Marshall Space Flight Center
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(PDS) - Mr. O.W. Murray (w/o encls.)

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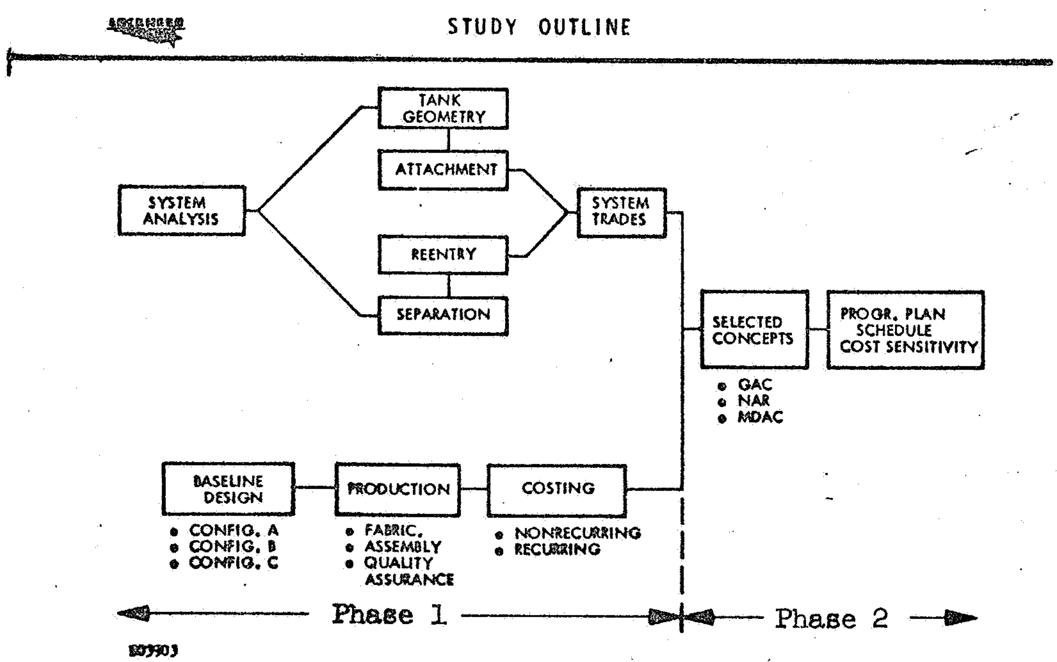
Section 1
INTRODUCTION

A Study of Alternate Space Shuttle Concepts was conducted by the Lockheed Missiles & Space Company under Contract NAS 8-26362 to examine the stage-and-one-half concept and its potential for later conversion and use in the two-stage reusable shuttle system. During the latter half of the study, an additional task (Task IV) was added. This task called for the study of external hydrogen tank concepts as used in connection with the external hydrogen tank orbiter, and was focused primarily on the issues involved in the design and production of a low-cost expendable tank system utilizing the results of extensive studies of droptank concepts performed for the stage-and-one-half space shuttle system.

The study task was performed in three months (1 April to 30 June, 1971) and had to be conducted in parallel with three other simultaneously ongoing studies of external tank orbiter systems performed by GAC, NAR, and MDAC. In order to cope best with the continuously shifting state of definition of external tank orbiters, the study was divided into two phases, as shown in the figure below.



In the first phase (2 months) emphasis was on two activities: (1) conducting a system analysis study, leading to the establishment of design requirements, and (2) performing a detailed design, manufacturing and cost analysis of typical candidate tank configurations, based on the GAC droptank definition as it existed at the beginning of the study. In the second phase of the study (1 month), the results of the first phase were applied to the most recent state of definition of the three external tank orbiter studies and a typical program plan and schedule were developed.

This final report of the study is divided into four parts plus a separately published appendix:

Part I – System Analysis. This part describes the results of studies performed to establish initial conditions for separation, retrorocket, and entry analyses. It defines the influence of various tank geometries, nose fairings, attachment concepts, and intact or nonintact entry on system performance, weight, and cost utilizing a consistent tradeoff methodology. The results are partially in parametric form for use in later design applications and partially in specific form leading to a preliminary summary of droptank design requirements.

Part II – Baseline Design Description. This part describes the definition of a baseline design based on requirements derived from the GAC external tank orbiter configuration definition existing at the beginning of the study (1 April 1971). It describes the derivation of three baseline candidate designs (Configurations A, B, and C) utilizing results of a materials and producibility analysis. It also describes the utilization of these three baseline designs in performing a detailed analysis of manufacturing and quality assurance concepts associated with these designs, leading to a bottom-up estimate of the total tank program cost for Configurations A, B, and C. The results of all tradeoff studies performed in Parts I and II are summarized at the end of this part, as ready reference for future applications.

Part III – Application Study. This part describes the application of the results of Parts I and II to three external tank orbiter configurations (GAC, NAR, and MDAC) as they existed at the beginning of the application study (1 June 1971). For the GAC and NAR configurations, it describes the resulting tank design and gives associated manufacturing and program cost estimates; and for the MDAC configuration a CER program cost estimate is given.

Part IV – Program Summary. This part describes a typical program plan and program schedule for the development and production of droptanks for external tank orbiter configurations, gives cost sensitivities to changes of program size, and relates costing results to CERs and droptank estimates from other studies.

Appendix. The appendix of this report contains all Engineering Memorandums generated during the study. They are presented in the order of the sections of the report to which they are applicable, and referenced in the report where they apply.

1.1 STUDY OBJECTIVES

The study had three major objectives:

- To establish realistic droptank program cost estimates by accomplishing detail tank design and manufacturing planning
- To estimate droptank program cost for selected specific designs
- To determine the change in program cost due to variations in design and manufacturing concepts and due to changes in program assumptions

Other objectives of study included:

- Comparison of various droptank geometries
- Comparison of various concepts of droptank attachment to the orbiter

- Comparison of intact with nonintact tank impact and determining its influence on design requirements and dispersion
- Evaluation of various tank materials
- Evaluation of joining methods for tank structure
- Definition of manufacturing and product assurance concepts for tank production

1.2 SUMMARY AND RESULTS

The essential findings and results of this study are summarized here to show how the study objectives were met and to give some interpretation of these results.

1.2.1 Cost and Cost Comparison

Three baseline tank designs (Configuration A, fusion-welded 2219-T81 aluminum; Configuration B, weld-bonded 2219-T87 aluminum; Configuration C, fusion-welded 301 stainless steel) were selected early in the study and used to perform the required design and manufacturing analyses to the depth necessary for accurate costing. Their selection was the result of defining the most promising materials and manufacturing concepts and was oriented toward determining the influence of materials (2219 aluminum or stainless steel) and joining methods (fusion-welding or weld-bonding) on total program cost. A summary of the program cost expected for developing and producing 900 tanks (of Configuration A, B, or C) in a 10-year period is given in Table 1-1.

Costing was based on a development span from 1972 to 1976 and a production span from 1977 to 1987. This bottom-up cost estimate utilizes 1970 labor rates and includes a 10 percent fee. The costing comprises DDT&E effort, production, logistics storage and ground handling equipment. Costs for the assumed assembly facility at KSC are not included.

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TOTAL PROGRAM COSTS ($ MILLIONS)

	CONFIGURATION A	B	C
NONRECURRING			
DDT&E	54	58	58
PRODUCTION	60	63	69
	114	121	127
RECURRING			
PRODUCTION	650	583	655
TOTAL	764	704	782

Table 1-1

D03880(1)

Table 1-1

Comparison of the three configurations shows that the cost of Configuration B (weld-bonded), is $60-million lower than that of Configuration A (fusion-welded) and $78-million lower than that of Configuration C (stainless steel, welded). Recurring costs constitute approximately 85 percent of the total program cost. The rest is distributed equally between DDT&E and nonrecurring production cost. Distribution of recurring cost is given in Table 1-2.

Comparing Configuration A with Configuration B shows that for the weld-bonded tank (B), fabrication and assembly is $51-million lower and raw materials are $5-million lower (due to using sheetmetal stock as processed without chem-milling as required for Configuration A). Comparing Configuration B with C shows that the structure fabrication and assembly cost for the weld-bonded tank (B) is $30-million lower and the material cost $42-million lower.

The effect of weight difference between tanks is small, so that the influence of weight does not change the cost comparison ranking.

From these comparisons, it is concluded that Configuration B, a weld-bonded aluminum tank, offers the lowest program cost and should be pursued, even though design criteria and process specifications for weld-bond application to liquid hydrogen pressure vessels still must be determined.

The results of these bottom-up cost analyses were compared with the existing LMSC cost estimating relationships (CERs) and were found to be in very close agreement (less than 1 percent difference). In addition, the study results were compared with results from an earlier study which defined droptank costs for the LMSC Stage-and-One-Half space shuttle configuration, as shown in Fig. 1-1. This figure shows that first unit costs for Configuration A fall in a reasonable region with a complexity factor of 0.85.

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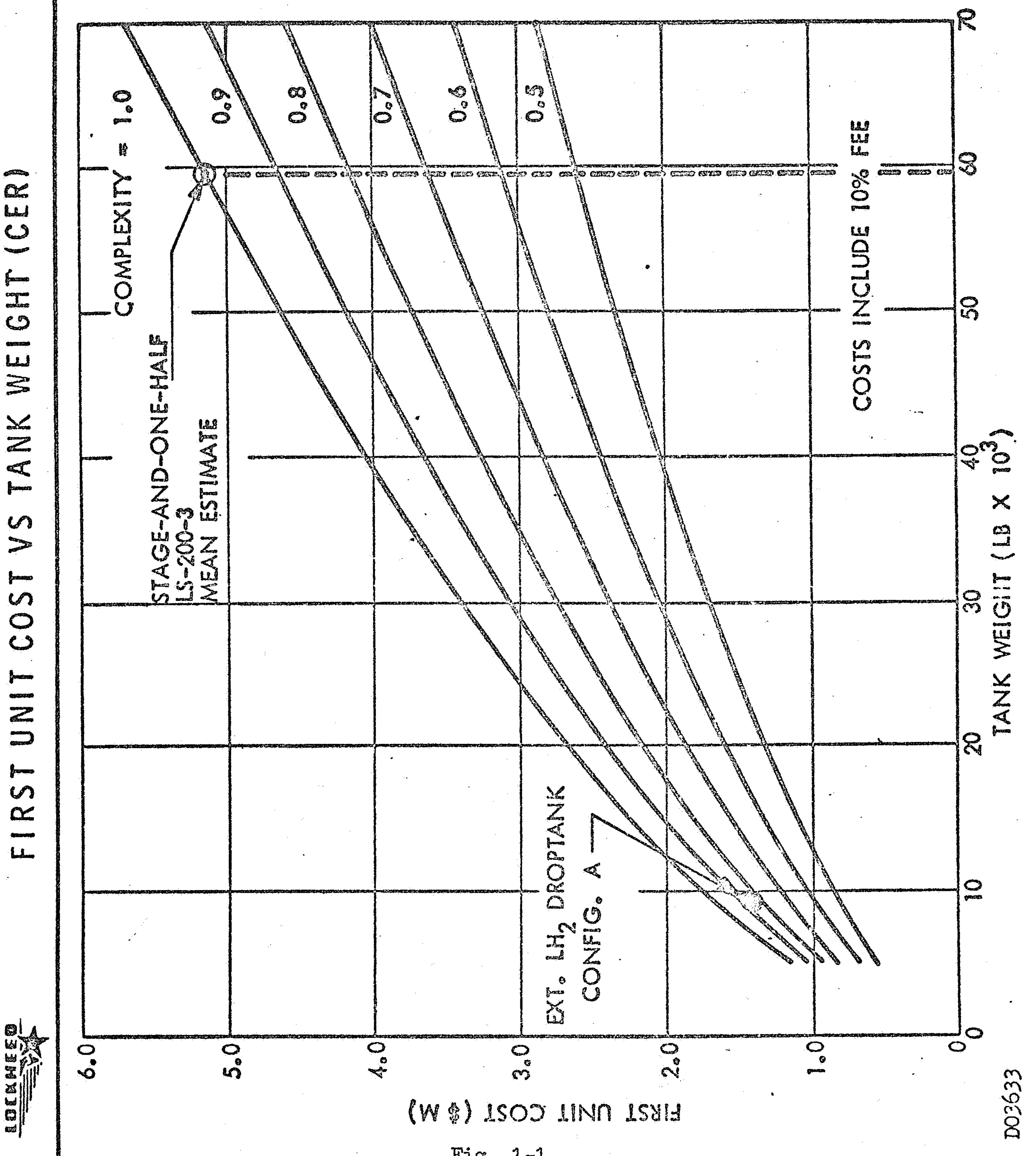
RECURRING COST DISTRIBUTION ($ MILLIONS)

	DESIGN CONFIGURATION				
	A ←	Δ	→ B ←	Δ	→ C
MANUFACTURING	423	56	367	32	399
• STRUCTURES FAB AND ASSY	(219)	51	(168)	30	(198)
• INSULATION	(56)		(56)		(56)
PRODUCT ASSURANCE	57		50		54
PROGRAM MANAGEMENT	8		8		8
SUPPORT ENGINEERING	3		3		3
RAW MATERIALS	67	5	62	42	104
PURCHASED COMPONENTS	92		93		87
TOTAL	650	67	583	72	655

Table 1-2

D03920

Table 1-2


FIRST UNIT COST VS TANK WEIGHT (CER)
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FIRST UNIT COST ($ M)
6.0
5.0
4.0
3.0
2.0
1.0
0
0
10
20
30
40
50
60
70
TANK WEIGHT (LB X 10^3)
COMPLEXITY = 1.0
0.9
0.8
0.7
0.6
0.5
STAGE-AND-ONE-HALF
LS-200-3
MEAN ESTIMATE
EXT. LH_2 DROPTANK
CONFIG. A
COSTS INCLUDE 10% FEE
D03633

Fig. 1-1

1.2.2 Results of Trade Studies

Concurrent with the design activities on the baseline tank, design analysis and element trade studies were conducted. A list of the essential results of these studies is as follows:

- Intact Entry

  In order to keep the tank impact dispersion as small as possible, entry is desirable and achievable by accepting a penalty in TPS weight. For sustained tumbling entry or entry at shallow angles-of-attack (approx. 15 deg) the TPS weight is about twice that required for ascent only. For entry angles-of-attack greater than 25 deg, the TPS weight will be about three times that required for ascent. This comparison is predicated on the assumption that only 30 percent of the tank surface area requires ablator protection during ascent. Because of the rather severe penalties associated with protecting aluminum tanks, it seems desirable to investigate further the utilization of stainless steel tanks for intact entry.

- Tank Fineness Ratio

  Relatively high tank fineness ratios (between 6:1 and 8:1) are desirable because composite ascent drag is reduced. This lower drag effect is enhanced by locating the tank at or near the orbiter wing trailing edge. This also reduces the booster pitch-trim requirement. However, it may result in a more complex orbiter attachment and cause base heating problems. A fineness ratio of 8:1 appears to be the practical upper limit because for values beyond this ratio, ascent bending loads begin to demand heavier tank gages than required by pressure alone. Ratios below 6:1 should be avoided because of substantial performance penalties.

- Tank Forward Geometry

Although a forward fairing between the tank and the orbiter would result in a composite drag reduction of approximately 5 percent, the weight and cost of the fairing and the installation complications offset this advantage. Wind tunnel tests indicate that addition of a tank fairing, while having a slight mitigating effect on peak heat rates, actually only relocates areas of high heat intensity instead of reducing them. Addition of a 15 deg blunted nose cone to the forward end of the tank provides an adequate solution with regard to ascent drag and heating and allows for an acceptable, if not optimum, entry shape.

- Tank Material

The selected tank material (in connection with weld-bonding) is 2219-T87 aluminum alloy, which combines good strength and fracture toughness with good welding characteristics, thereby yielding light-weight, low-cost designs.

- Joining Method

The joining method selected for tank manufacturing is weld-bonding. This method allows the use of aluminum sheets as procured, eliminating the chemical machining requirement associated with fusion-welding. Other advantages for this weld-bond method include use of half-standard sheet gage tolerances for a lighter weight design, relaxed sheet trim tolerances for lower fabrication costs, and higher efficiency joints for greater strength and leak prevention.

- Pressure-Stabilized Tank

The lightweight pressure-stabilized thin-walled tank was found to be the most economical design, even though a strongback with built-in pressurization and tank stretch system is required for ground handling and storage.

- Hydro-Pneumostatic Proof Pressure Test

  This concept, which provides adequate simulation of stress levels at ambient temperatures, is the most economical solution to acceptance testing when compared with normal proof pressure tests at ambient temperatures (heavier tanks) and proof pressure testing with cryogenic fluids (expensive).

- Expendable Tank Attach Structure

  A lightweight, expendable tank attach structure is economically preferable to a heavier, reusable structure which retracts into the orbiter.

- Pyrotechnic Feedline Separation

  This type of separation for the 14-inch feedlines is economically and weight-wise superior to a heavier, reusable quick-disconnect valve.

- Reusable Vent/Pressure Lines

  Reusable vent/pressure lines located in the orbiter are relatively lightweight and show a cost advantage even when assuming a relatively high maintenance cost.

- Retrorocket

  A comparison of existing solid propellant rockets with postulated new retrorocket motor designs shows the latter to be substantially lighter and more cost-effective in spite of the required development. Locating the rocket in the rear of the tank proved best because it provides protection of the nozzle/TPS interface during trimmed entry (of no concern for tumbling entry) even though it requires greater orbit maneuvering.

- High-Rate Tank Separation

  The use of a high-pressure gas generator/piston separation device provides a lightweight system and also allows for a relatively high separation velocity (approximately 30 fps). This gets the tanks away from the orbiter quickly and allows retro-fire before attitude errors accumulate.

1.2.3 Application of Study Results

Results of system analysis, baseline design definition, and baseline costing were applied to the GAC and NAR external tank orbiter configurations as they existed on 1 June 1971 (see Fig. 1-2). The positions developed during these studies led to the formulation of the assumptions shown in Table 1-3 for the conduct of the application study. These assumptions, together with the required tank volume and physical orbiter constraints, led to the orbiter/tank assemblies shown in Fig. 1-3. The orbiter/tank arrangement for the modified GAC concept is very similar to the recent GAC configuration with the exception of the nose shape. The arrangement of the modified NAR concept is distinctly different from the present NAR configuration as a result of increasing the tank slenderness ratio from a value of 4.2:1 to a value of 7.3:1.

The structural design for the GAC and the NAR tank versions follows very closely the design concepts developed for the baseline Configuration B (weld-bonded). Subsystem definition is very similar to the definitions used for Configuration B except for the retrorocket system, which is now installed at the rear tank end.

Manufacturing and Quality Assurance efforts associated with the production of the modified tanks were estimated, using a detailed account of the changes incurred between the estimates for Configuration B and the GAC/NAR configurations for all nonrecurring and recurring activities. Based on these inputs, total program costs for the new tank concepts were estimated using the same

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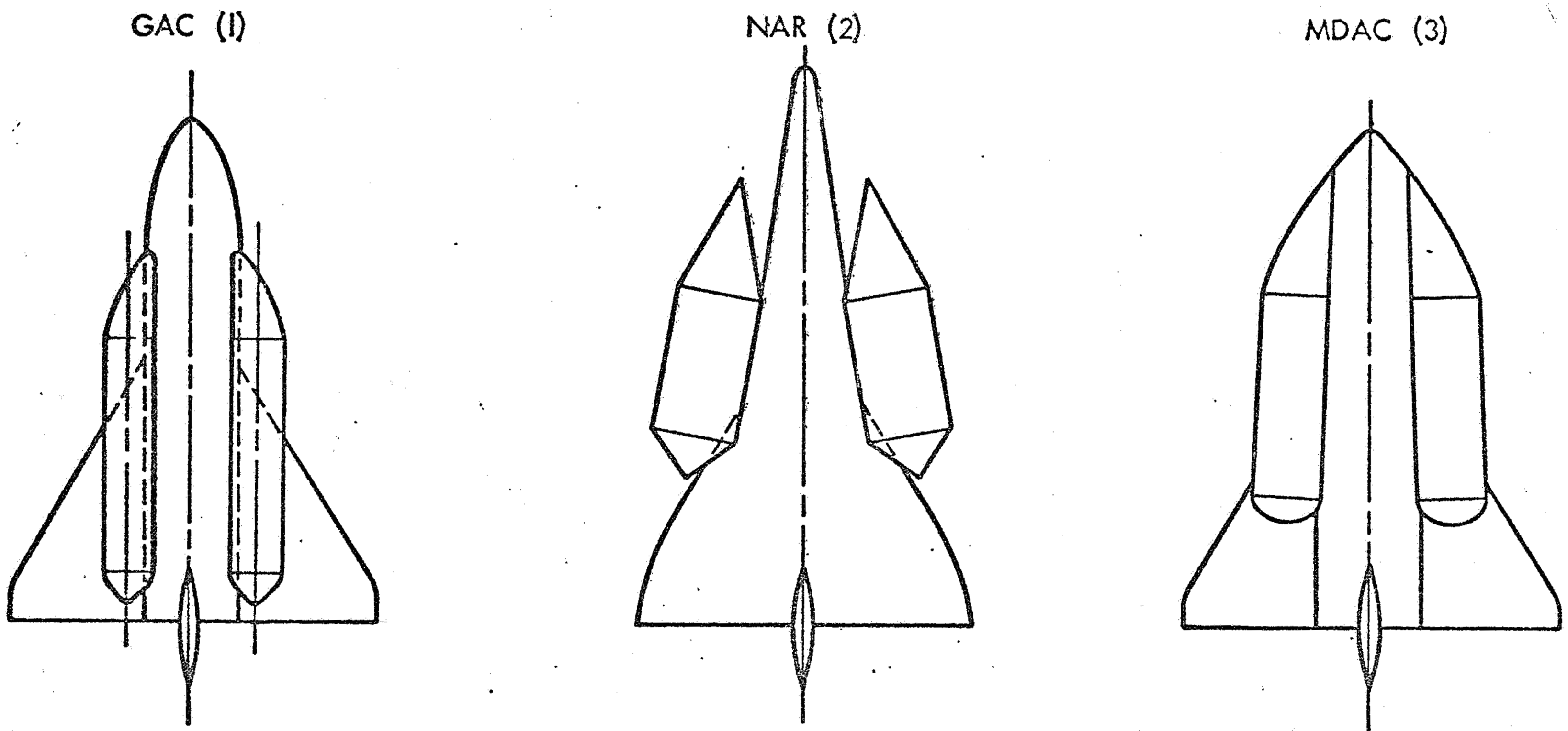
INPUTS FOR APPLICATION STUDY



	GAC (1)	NAR (2) CONCEPT 0021	MDAC (3)
TANK DIA	14.9 FT	17.2 FT	21.5 FT
TANK LENGTH	102 FT	71.5 FT	105.3 FT
TANK VOLUME	13,666 FT^3	12,804 FT^3	28,500 FT^3
TANK STRUCTURE WEIGHT	4,981 LB	9,920 LB	13,606 LB

SOURCE: (1) OVERVIEW AND STUDY STATUS, "EXTERNAL HYDROGEN TANK ORBITER, HEAT SINK BOOSTER," 28 APRIL 1971
DRAWING 552LO190-511
(2) MIDTERM REVIEW, "ORBITER EXTERNAL HYDROGEN TANK STUDY," 12 MAY 1971
(3) THIRD STATUS REPORT, "EXTERNAL TANK STUDY," 25 MAY 1971

D03912(1)

Fig. 1-2

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APPLICATION STUDY DESIGN ASSUMPTIONS

- WELD-BONDED DESIGN (CONFIGURATION B)
- ALUMINUM 2219
- TANK L/D – 8
- STRAIGHT CONE
- INTACT IMPACT
- PRESSURE-STABILIZED TANK
- EXPENDABLE TANK ATTACH STRUCTURE
- REUSABLE VENT PRESSURE LINE
- PYROTECHNIC TYPE FEEDLINE SEPARATION
- NEW RETROROCKET – AFT INSTALLATION
- HYDROPNEUMATIC PROOF PRESSURE TEST

Table 1-3

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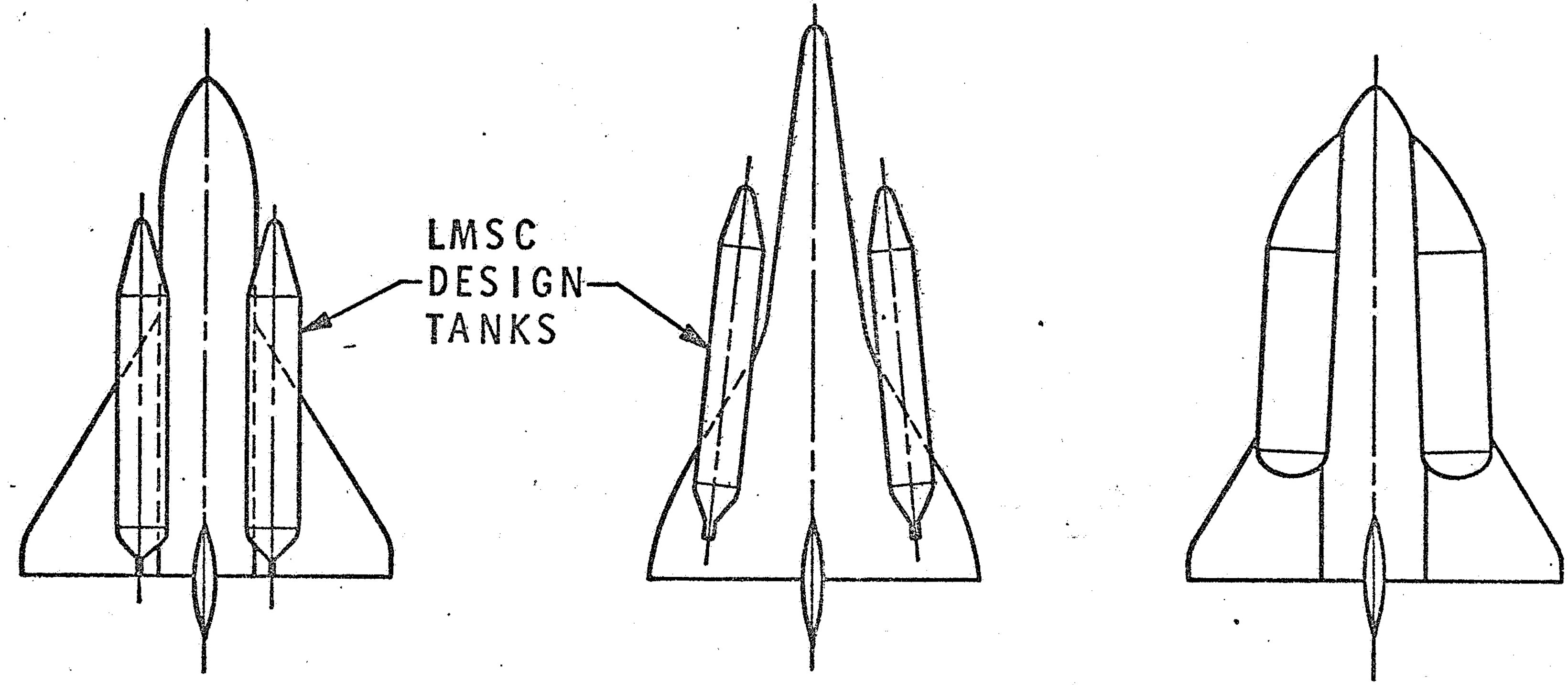
Table 1-3

TANK/ORBITER ASSEMBLY - LMSC



	GAC	NAR	MDAC
TANK DIA	15 FT	14 FT	21.5 FT
TANK LENGTH	98.3 FT	103 FT	105.3 FT
TANK VOLUME	13,666 FT^3	12,804 FT^3	28,500 FT^3
TANK STRUCTURE WEIGHT	3,516 LB	3,364 LB	13,606 LB

Fig. 1-3

D03892

costing assumptions used during the baseline costing. The results are summarized in Table 1-4. The summary shows also the total program cost estimated for the specified MDAC configuration using unmodified MDAC design and weight estimates and in this case, applying the updated LMSC CER developed for fusion-welded tanks (the MDAC design concept).

1.2.4 Program Plans and Problems

Preliminary program planning for all elements of the droptank program was performed to the extent necessary to perform a bottom-up costing exercise; these plans were developed in connection with a relatively relaxed LH_2 Tank Master Schedule (Fig. 1-4), utilizing time spans required to develop the space shuttle orbiter system. No attempt was made to define minimum development time; however, it is felt that a development time of 2-1/2 to 3 years would be adequate to produce the desired results. This estimated span assumes that critical technological and programmatic issues will find early attention. Essential technical issues are summarized in Table 1-5.

The weld-bond process with its promise of at least $60 million program cost reduction has been long used in primary aircraft structures (Russia) and most recently in the manufacture of the Centaur Shroud (LMSC). However, it must be confirmed for use in LH_2 tanks, and the required design criteria and process specifications must be developed early to avoid costly program changes.

The Thermal Protection System for ascent and entry protection constitutes a high share of the total tank program cost (10 to 20 percent) and is an area of great uncertainty concerning the integrity of the system during the various flight phases. Early definition of design criteria and processes is also required.

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DROPTANK DESIGN APPLICATION STUDY RESULTS

MAJOR PROGRAM PARAMETERS	TANK DESIGN		
	ALUMINUM, WELD-BONDED		ALUMINUM, FUSION-WELDED
	GRUMMAN	NORTH AMERICAN	MCDONNELL/DOUGLAS
TOTAL TANK WEIGHT	22,132 LB	20,928 LB	44,982 LB*
DDT&E COSTS	$128M	$127M	$171M**
RECURRING PRODUCTION COSTS	$660M	$635M	$1197M**
TOTAL TANK COST	$788M	$762M	$1368M

* PER MCDONNELL-DOUGLAS COMPANY THIRD STATUS REPORT – EXTERNAL TANK STUDY, 25 MAY 1971

** DETERMINED BY LMSC CER

D03853

Table 1-4

Table 1-4

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LH_2 TANK MASTER SCHEDULE

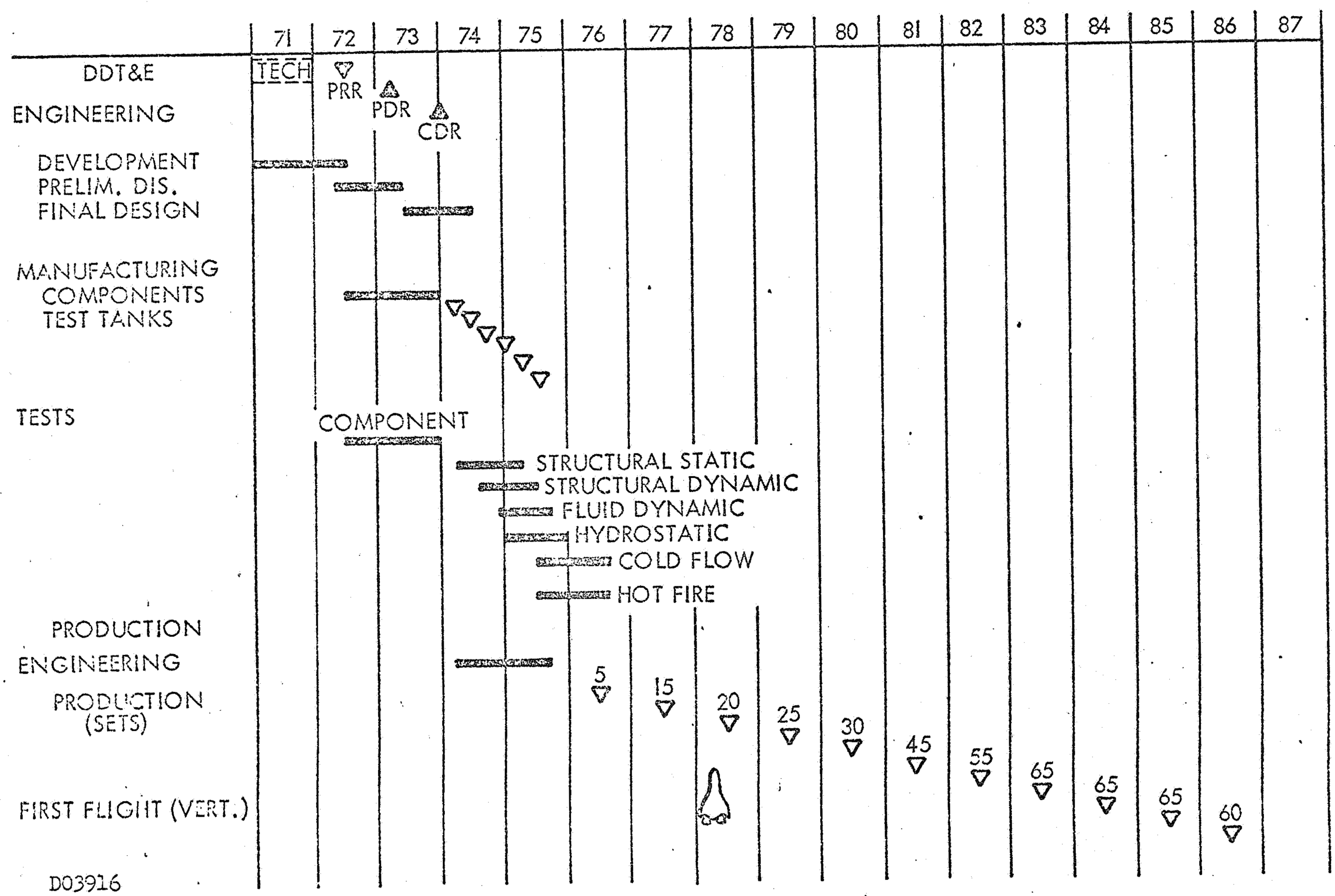

Fig. 1-4

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DROPTANK DEVELOPMENT ISSUES

• WELD-BOND CONCEPT (FOR LH_2 APPLICATION)	OFFERS	\$60 MILLION PROGRAM COST REDUCTION
	NEEDS DEVELOPMENT OF:	– MOST EFFECTIVE JOINT – LOW-COST WELDING CONCEPT – LOW-COST INSPECTION & REPAIR TECHNIQUE – SUBSCALE TEST CONFIRMATION – DESIGN/PROCESS SPECS FOR LH_2 APPLICATION
• THERMAL PROTECTION SYSTEM FOR ASCENT OR ASCENT/ENTRY	CONSTITUTES	\$60 MILLION OR \$110 MILLION SHARE OF PROGRAM COST
	NEEDS DEVELOPMENT OF:	– MOST EFFECTIVE INSULATION CONCEPT – RELIABLE METAL/FOAM/ABLATOR BONDS – CLOSE TOLERANCE FOAMING/MACHINING TECHNIQUE – LOW-COST INSPECTION & REPAIR TECHNIQUE – SUBSCALE TEST CONFIRMATION – DESIGN/PROCESS SPECIFICATIONS

Table 1-5

D03915

Table 1-5

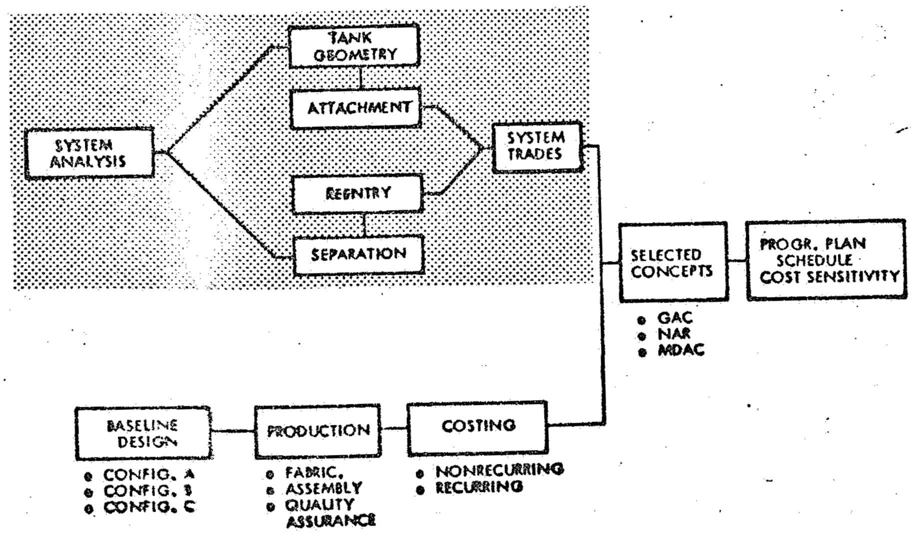
PART I

Part I
SYSTEM ANALYSIS

Part I describes the system analysis activities highlighted in the figure below. These analyses concentrated on four primary analytical activities:

- Ascent Analysis
- Tank Geometry Optimization
- Tank Separation
- Tank Retro and Entry

The ascent analyses were performed in order to adequately establish the initial conditions for performing the separation, retro, and entry analyses. The tank geometry optimization focused on the effect of varying tank fineness ratio with nose shape treated separately. Separation design concepts were studied in conjunction with the structure attachment design studies and concurrent with the separation parametric analysis. Retrorocket parametrics were analyzed in concurrence with the 3D and 6D deorbit and entry simulations. These studies were performed to provide design and engineering guidelines and/or requirements for subsequent tank studies. The results are presented partially in parametric form for later use and, where applicable, total system evaluations were performed to identify the impact of certain selections.



Section 2
SYSTEM ANALYSIS

2.1 ASCENT ANALYSES

The ascent analyses were conducted to establish firm conditions for the subsequent separation, deorbit, and entry analyses. In addition, the effect on orbiter injection weight as the composite drag varies due to changes of the droptank fineness ratio was analyzed. Aerodynamic studies provided the basic ascent aero characteristics and also evaluated the effects of varying tank location and geometry.

During ascent flight, external tanks mounted on the side of the orbiter are the source of significant interference forces and moments. The tanks, for example, create a tank interference drag at Mach 1.2, which is three times that of the isolated tanks. At Mach 1.2, NASA-Ames test results show the drag of the tanks plus interference is 20 percent of the composite ascent vehicle drag, whereas drag of the isolated tanks has been estimated to be only 7 percent of the total. Because of the direct impact of drag on ascent performance, payload, etc., aerodynamic analysis was concentrated on effects of design changes on drag reduction. These analyses are reported in EMs L2-12-01-M1-9, L2-12-01-M1-1, and L2-12-01-M1-2 (see Appendix).

Ascent aerodynamic design analysis concentrated on reducing drag by consideration of:

- Tank Configuration Design – To reduce drag of the tank itself and perhaps interference drag
- Tank Location – To reduce interference drag
- Fairings – Reduction of tank and/or interference drag

Secondarily, the effects of tank-induced pitching moment have also been studied.

2.1.1 Tank Drag Analysis

Design variables for reducing tank drag can be listed as:

- Tank nose contour
- Tank fineness ratio
- Boattail fineness ratio

These results show that benefits due to increasing the tank fineness ratio above 9 or 10 yield a diminishing return. Increasing tank fineness ratio from 6.07 to 8.0 is estimated to decrease composite vehicle drag by 3.5 percent.

Fairing designs which produce the most efficient slender boattail were estimated to give less than 1 percent reduction in composite vehicle drag. On the other hand, changing from the wind-tunnel-tested biconic tank nose shape to a single 20-percent blunted 15° cone is estimated to give a reduction in the ascent vehicle drag coefficient of ~1.8 percent at Mach 1.5.

A detailed study of the effects of optimizing beyond the 15-deg conical nose contours was not warranted, since additional drag reduction from this source should also be less than one percent of the composite vehicle drag.

<u>Tank Location.</u> The effects of moving the LH_2 tanks to an aft fuselage position were measured in the NASA-Ames 6 x 6 test facility (see EM L2-12-01-M1-9). The test results show that the drag of the tanks (measured by a separate balance) was reduced 23 percent at Mach 1.2 due to an aft fuselage installation. The effects of moving the tanks spanwise were roughly estimated; however, penalties imposed on wing structural weight, plumbing weight and complexity, etc., would outweigh improvements in drag. Even with tanks placed at the wing tips, the installed drag is still of an order twice that of the isolated tanks.

2.1.2 Tank Fairings

NASA-Ames test results show that a 25-deg asymmetrical conical fairing placed over the 24-deg/12-deg biconic tank nose reduces the drag of the tanks by 42 percent at Mach 1.2; however, there is a much smaller effect (10 percent) on reducing interference drag on the orbiter. The increased weight of such fairings may negate any payload benefit due to reduced drag.

EM L2-12-01-M1-9 presents a bar chart showing the magnitude of drag reduction due to various design considerations. These bar chart values are repeated here (plus others) and relate to effects on payload. Net payload increase must, of course, be traded off against the weight increment due to such changes. The following table shows the potential payload gains when considering various tank-orbiter configuration changes.

Design Area	Percent Ascent Vehicle Drag Reduction	Gross Payload Increase
Tank Nose Fairing	5%	1,250 lb
Aft Fuselage Location	2.3%	550 lb
Wing Tip Location	5%	1,250 lb
Tank Fineness Ratio 8.0	3.5%	850 lb
Optimizing Tank Nose Contour	<1%	200 lb
Tank Boattail Fineness Ratio	<1%	200 lb
From Biconic to Single 15° Conical Nose	1.8%	450 lb

The above values are not additive.

2.1.3 Normal Force/Pitching Moment

Results from NASA-Ames tests were analyzed for effects of the tank on normal force and pitching moments (see EM L2-12-01-M1-9). The tanks themselves do not have a large effect for angles-of-attack to 10 deg; however, the interference effects acting on the orbiter are significant. At 6-deg angle-of-attack, M = 1.2, the normal force contribution of the tanks is zero, while the interference normal force acting on the orbiter is 21 percent of the orbiter normal force. Because of the positive normal force increment and a negative pitching moment increment, these interference effects apparently act over the orbiter wing in the tank base region. Movement of the tank (or tank base) to an aft position should alleviate this effect, whether the tank nose is relocated or not.

Figures 2-1 and 2-2 show the effect of the LH_2 tanks on the composite vehicle longitudinal characteristics at Mach 1.2 and in addition show the effect of deflecting the main booster engines. It is seen that with tanks "OFF" the required engine deflection to trim at zero normal force is 0.33 deg δ_E, whereas with the tanks "ON" the required engine deflection to trim is 2.33 deg δ_E, an increase of 2 deg. The basic aerodynamic data for zero engine deflection were obtained from NASA-Ames test results 66-551. The contributions of the engine to normal force and moments are based on the following assumptions:

- Booster Engine Thrust = 5.6×10^6 lb
- Booster Nozzle Base Located 83.7 ft from C.G.

It is felt that the unfavorable effect of the tanks can be reduced by moving the tanks to an aft position with tank base located at the orbiter wing trailing edge.

2.1.4 Aerothermodynamics

Aerodynamic heating wind tunnel data obtained by Grumman (GAC) and McDonnell-Douglas (MDAC) were examined to determine the effect of tank geometry and placement on thermal protection system requirements. The GAC data were obtained with thermocouple models and temperature-sensitive paint tests in the Langley Continuous Flow Hypersonic Tunnel*. MDAC data were obtained in the Cornell Aeronautical Laboratories 96-in. Shock Tunnel.** Comparison of these data

* LaRC Continuous Flow Hypersonic Tunnel Test Data on GAC Configurations, Transmitted to LMSC, April 1971.
** 3rd Status Report, External Tank Study, Presented to MSFC, 25 May 1971.

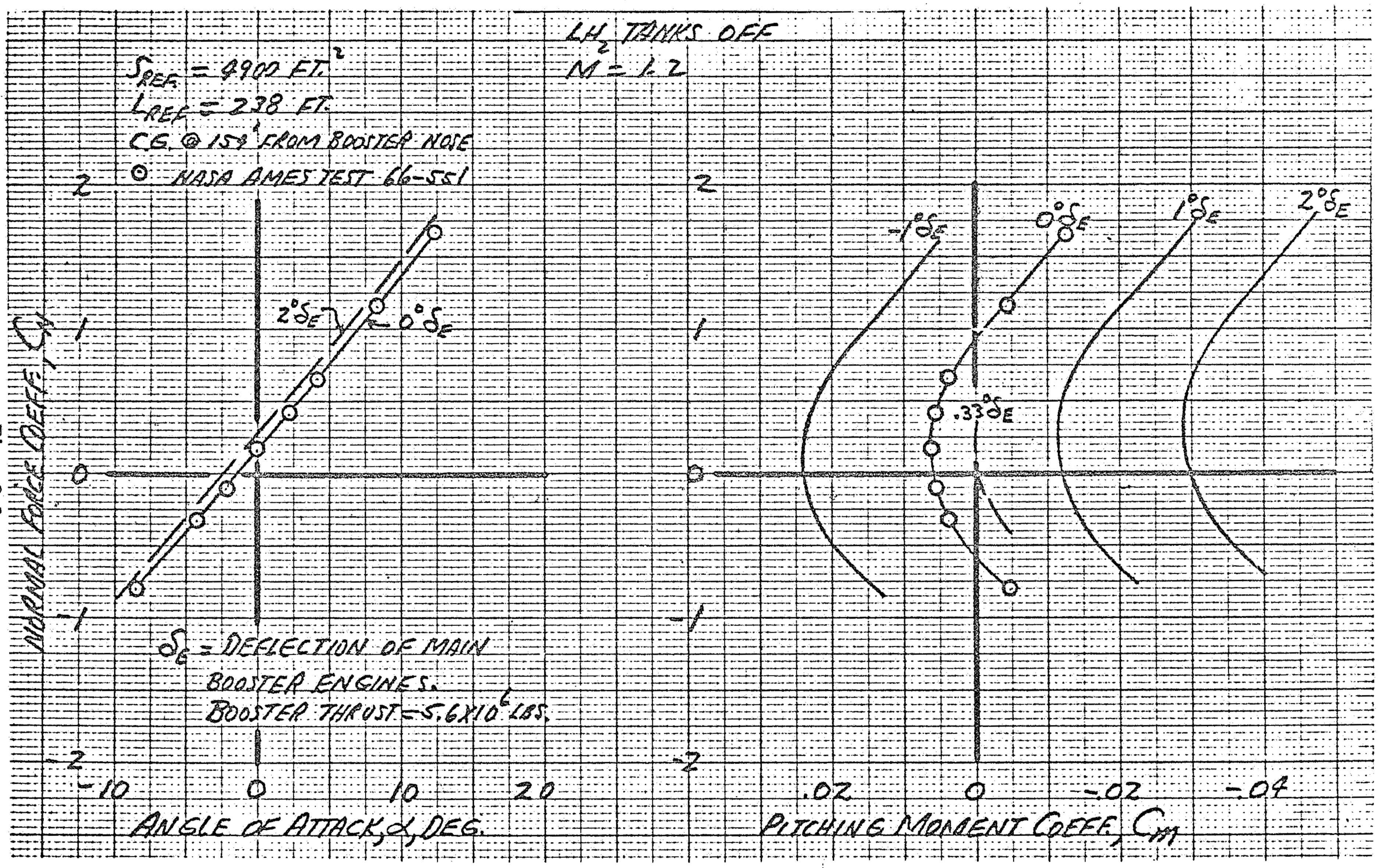


Fig. 2-1 Longitudinal Stability/Control - Composite Ascent Vehicle

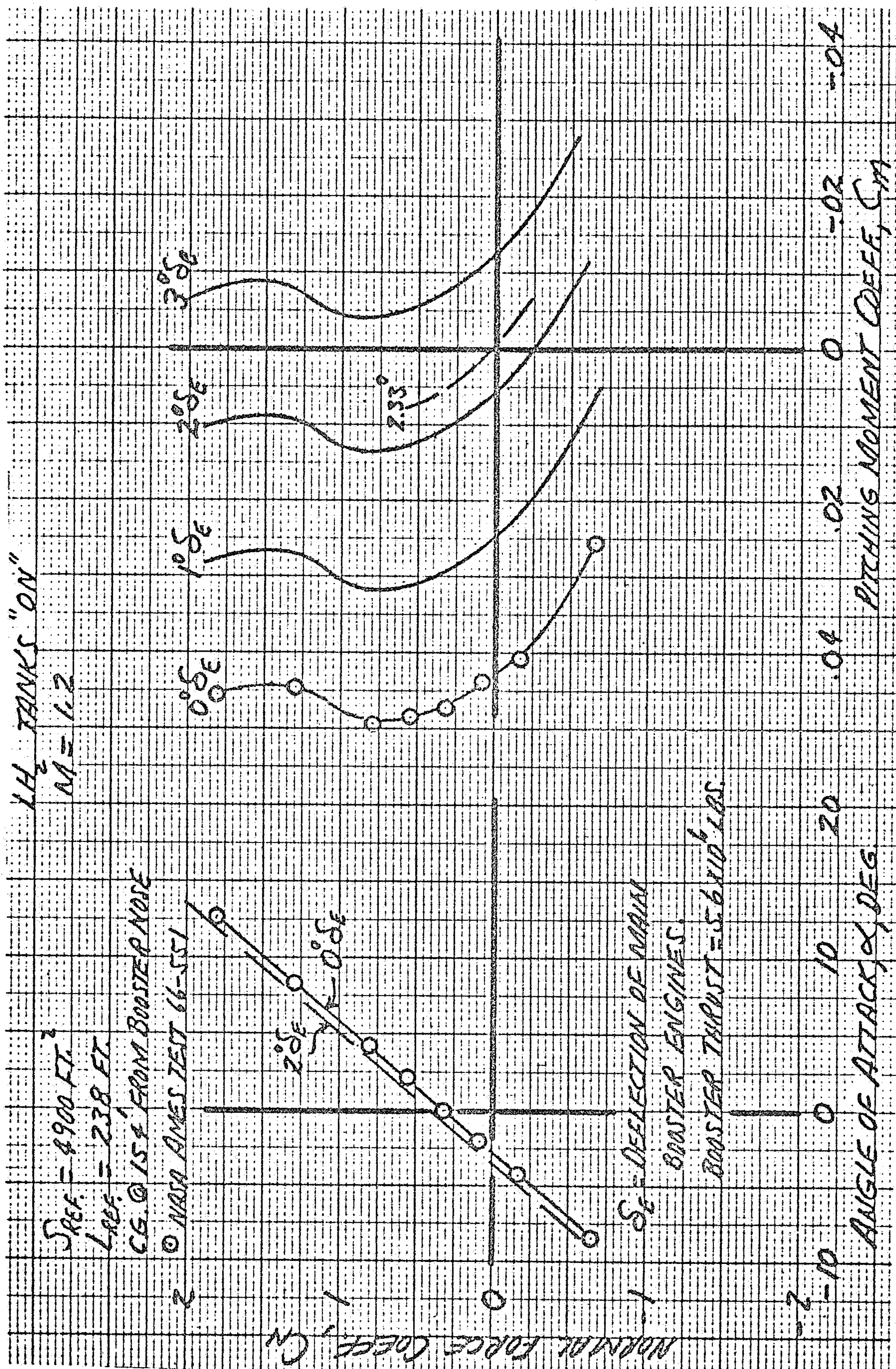


Fig. 2-2 Longitudinal Stability/Control - Composite Ascent Vehicle

Fig. 2-2

for axisymmetric tanks and tanks using faired (asymmetric) nose sections showed that although interference heating levels on the orbiter fuselage were reduced somewhat in magnitude, these areas were not eliminated but rather reappeared in different locations. The MDAC data in particular showed large heating increases in several regions associated with the faired design. Additionally, interference heating on the wing, aft orbiter fuselage, and on the tanks does not appear to be reduced by a nose fairing. Elimination of interference heating at these locations is not likely unless complete shrouding of the tanks and orbiter wing and fuselage could be accomplished. Finally, accurate prediction of interference heating levels is severely complicated by the large number of variables involved. These variables include Mach number, Reynolds number, boundary layer state (laminar, turbulent, or transitional), and enthalpy level (real gas effects). The test data obtained to date are considered preliminary and considerable additional testing will be required before the interference heating levels can be established with certainty.

As a result of the above considerations, it is concluded that the use of drop-tanks with an asymmetric nose fairing only offers, at best, a minimal reduction in TPS weight. This potential benefit is felt to be outweighed by aerodynamic, manufacturing, and cost considerations.

2.2 ASCENT TRAJECTORY ANALYSES

Ascent trajectory analyses were performed for basic mission requirements for inclinations of 28.5 deg, 55 deg and 90 deg out of ETR and for 90 deg out of WTR. All boost ascent trajectories were for injection into a 50 x 100 nm orbit.

2.2.1 Earth Oblateness Effects On Velocity Requirements

The effects of earth oblateness were analyzed and reported in EM L2-02-05-M1-7 (see Appendix). This analysis showed that both the ascent impulse and injection velocity vary with launch site and inclination when accounting for earth oblateness. Table 2-1 shows a comparison of injection velocities with and without the effect of earth oblateness.

Table 2-1

PERIGEE VELOCITY COMPARISON FOR 50 X 100 NM ORBITS

Launch Site	Orbit Inclination, (deg)	Injection Velocity (fps)		ΔV Difference, (fps)
		Spherical Rotating Earth	Oblate Rotating Earth	
ETR	28.5	25,869	25,892	23
ETR	55.0	25,871	25,879	8
ETR	90.0	25,873	25,883	10
WTR	90.0	25,873	25,887	14

The velocity difference is greater still when drag on the vehicle during transfer (coast) is ignored. These points are highlighted in Fig. 2-3. Note that the velocity difference (when ignoring drag) ranges from 23 to 36 fps.

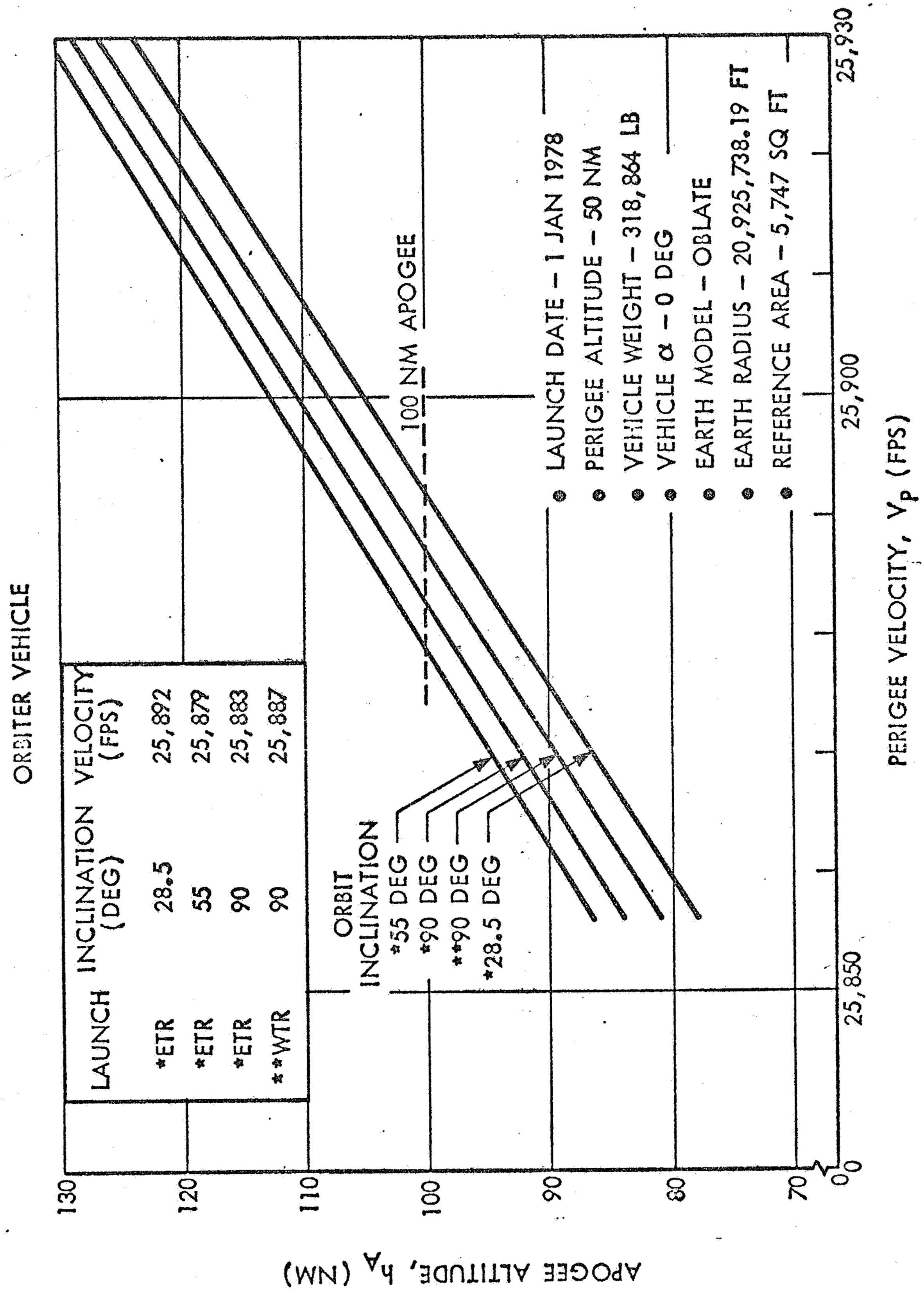


Fig. 2-3 Apogee Altitude Vs Perigee Velocity for Orbiter Vehicle

Fig. 2-3

2.2.2 Nominal Ascent Trajectories

The ascent trajectory data are reported in EM-L2-02-05-M1-7 (See Appendix). The Booster/Orbiter/Droptank configuration used in this study was furnished by NASA, and has a launch weight of 4.25M lb for all cases with a corresponding 1.35 thrust-to-weight ratio (T/W) at launch. The launch trajectory simulations were generated using the Lockheed PRESTO program. All trajectories were optimized for injection into a 50 x 100 nm orbit representing launches from ETR (inclination, I = 28.5, 55, and 90 deg) and WTR (I = 90 deg). A summary of injection conditions for each trajectory is presented for a nominal tank configuration designated by a fineness ration, $\ell/d = 6.07$. Also, summary data for tank geometry changes to evaluate tank configuration (drag) effects on ascent and injection conditions are presented.

Trajectory constraints assumed in the analysis included flight path optimization and lateral loading limitations ($\bar{\alpha} q = 1000$ deg-psf), both accomplished with pitch attitude control throughout ascent and a 3g longitudinal acceleration limit. The acceleration limit was accomplished by throttling the booster and orbiter engines, as needed, to maintain 3 g.

Droptank geometry variations assumed ℓ/d changes for a given (constant) volume. Nominal tank $\ell/d = 6.07$; assumed variations were $\ell/d = 14.5$ for the minimum drag configuration and ℓ/d 3.5 for the maximum drag configuration. This effect is shown in Fig. 2-4.

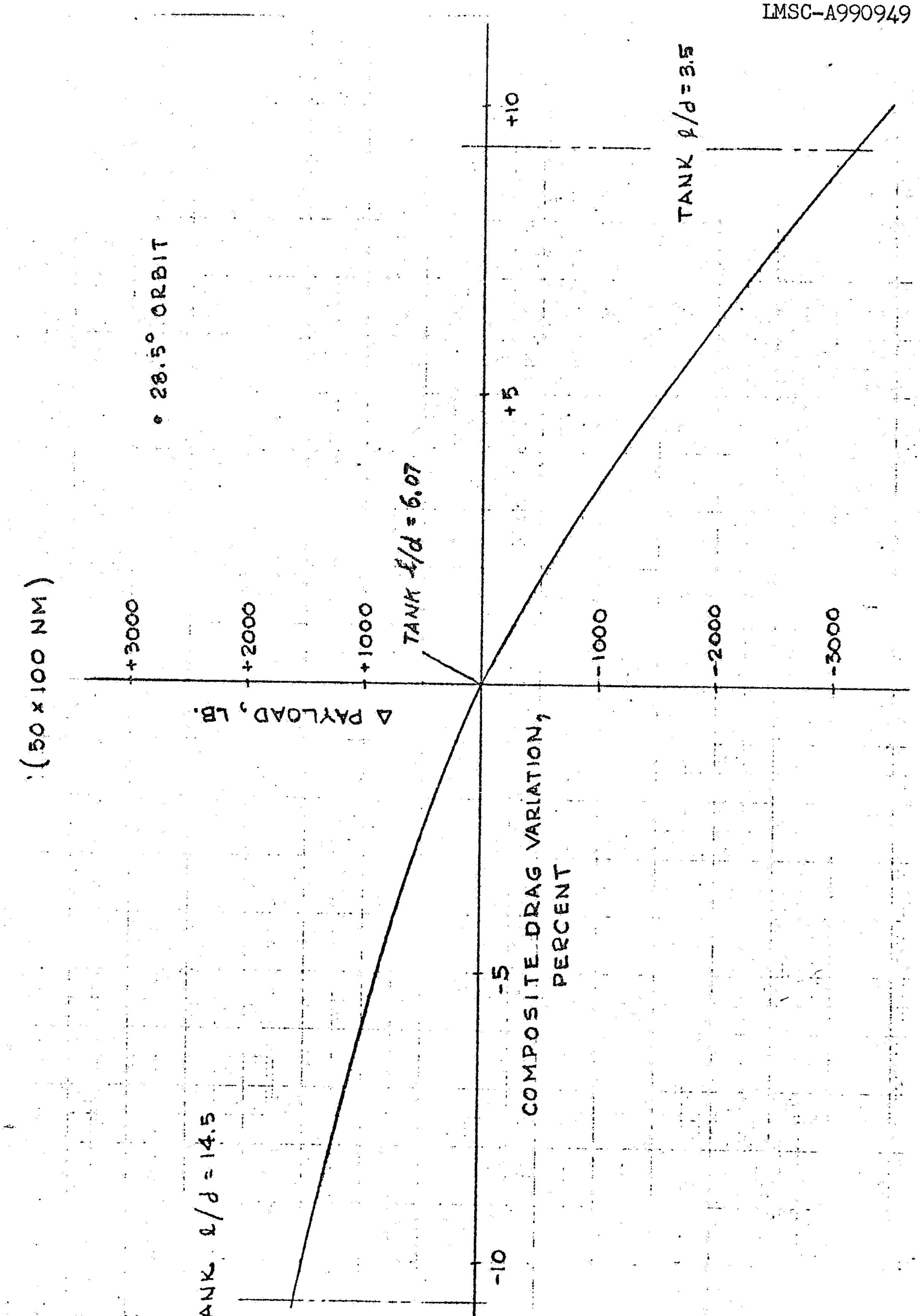


Fig. 2-4 Effect of Drag Variation on Payload

Fig. 2-4

Section 3

ORBITER-DROPTANK CONFIGURATION ANALYSIS

An optimization of tank fineness ratio was accomplished for L/D ratios ranging from about 3.5 to 14.5. The effects of tank nose shape, fairings, and relocation were also analyzed.

3.1 FINENESS RATIO OPTIMIZATION

The tank configuration that was used in the optimization analysis is shown in Fig. 3-1. The tank volume was held constant at 10,300 cu ft. The data are for a 55-deg inclined orbit mission, and it is assumed that internal pressure designs the tank. This assumption is valid for fineness ratios up to about 8:1. The early analysis reported in EM L2-12-M1-2 (see Appendix) indicated that the ascent load boundary was at a fineness ratio of about 11:1. Subsequent analysis shows this boundary to be too optimistic.

There are four main weight contributors to the optimization analysis: (1) composite drag variation, (2) tank weight, (3) structure support weight, and (4) insulation and TPS weight. Of the four, the drag has the greatest effect and the attach structure has the least. The results are shown in Fig. 3-2. It is estimated that ascent bending loads would become a design consideration at a diameter of about 12 to 13 ft. This diameter range is consistent with the orbiter interface requirements. The curves show that a potential payload gain of about 500 lb is available if greater fineness ratios are achievable (i.e., greater than the baseline of 6:1). This, of course, must be resolved with consideration to the orbiter interface attachment.

INSTALLATION AND TANK GEOMETRY

GRUMMAN DROPTANK SKT 100703

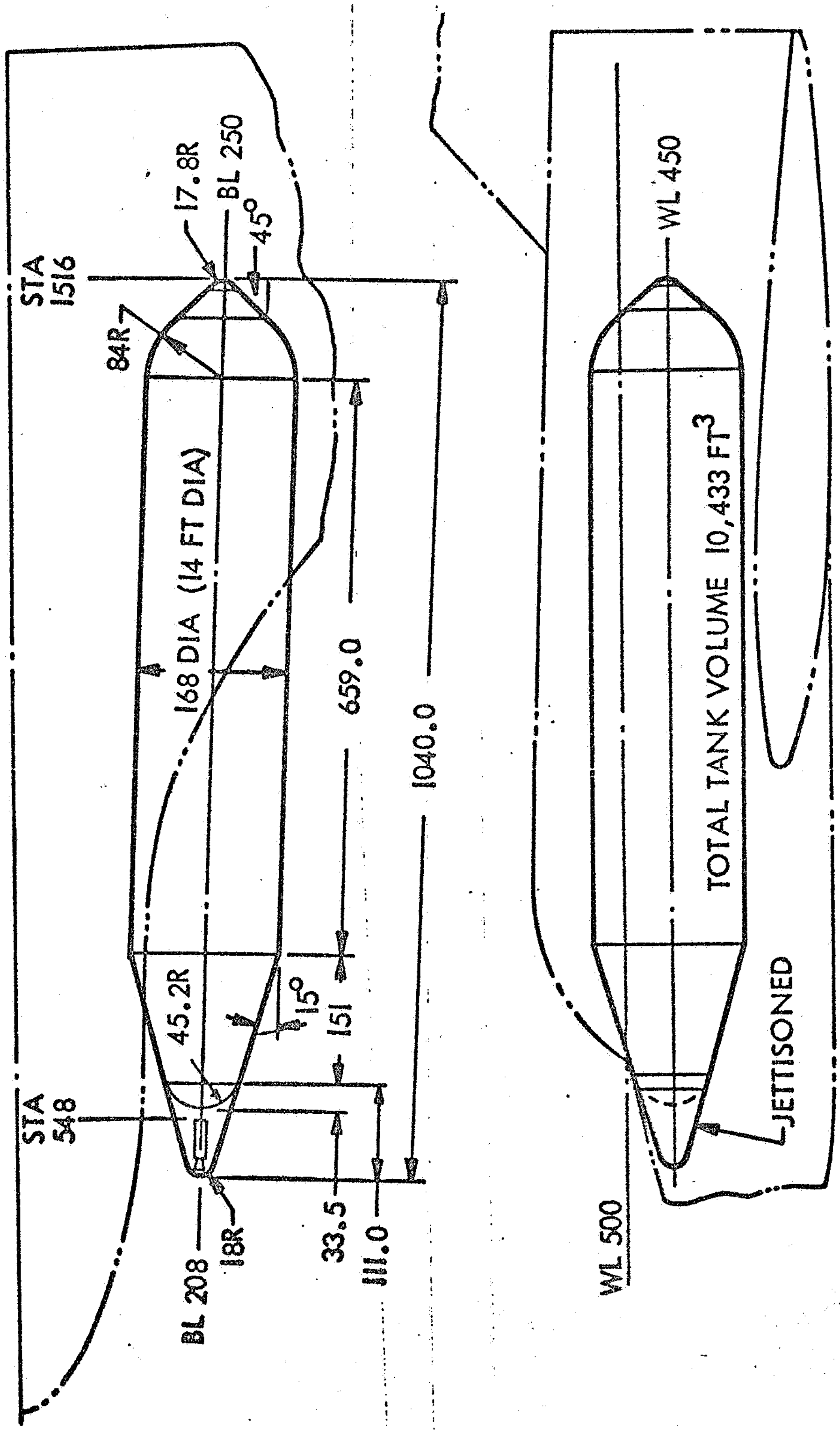
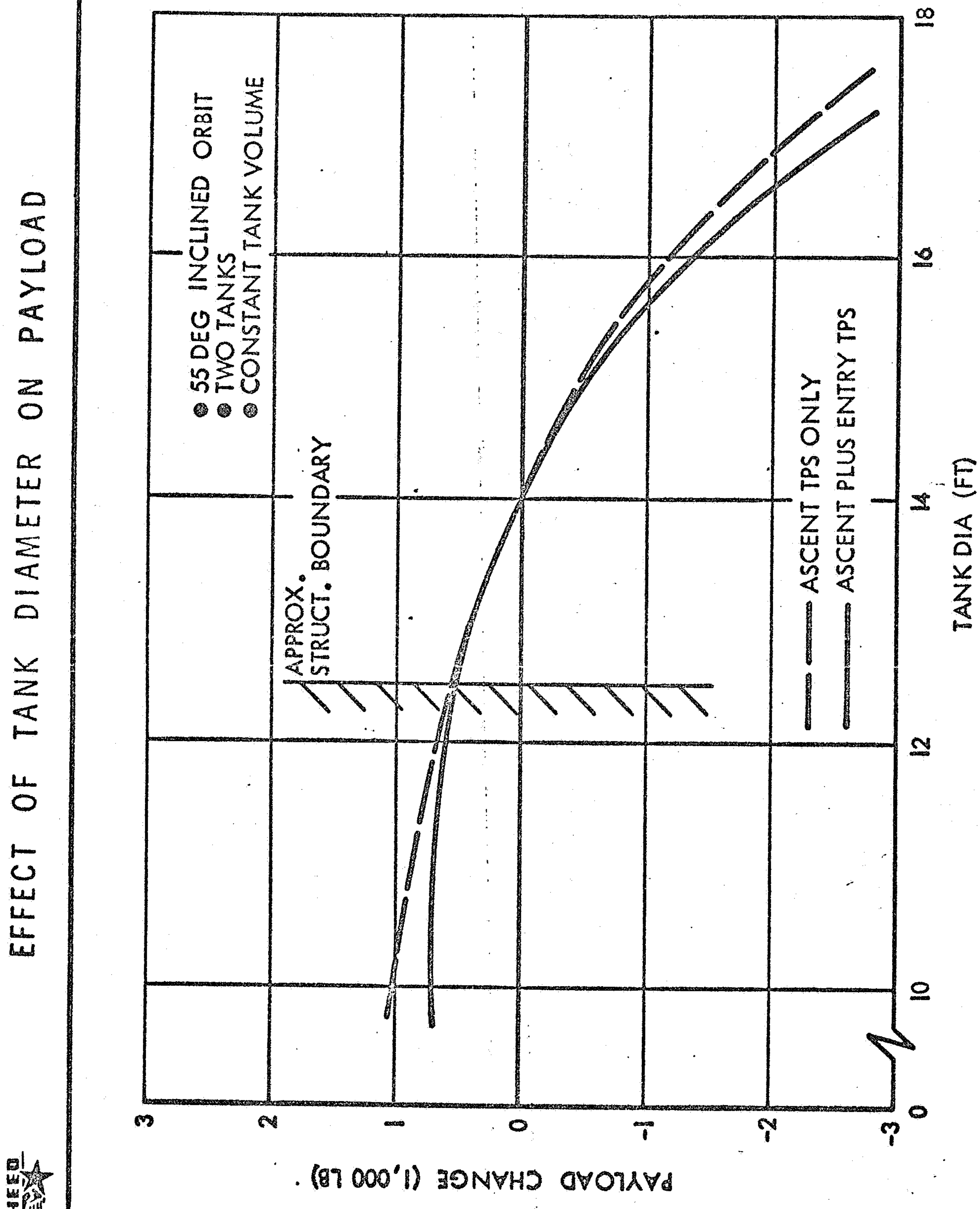


Fig. 3-1

D03829

LOCKHEED

Fig. 3-1



EFFECT OF TANK DIAMETER ON PAYLOAD
LOCKHEED
55 DEG INCLINED ORBIT
TWO TANKS
CONSTANT TANK VOLUME
APPROX.
STRUCT. BOUNDARY
ASCENT TPS ONLY
ASCENT PLUS ENTRY TPS
PAYLOAD CHANGE (1,000 LB)
3
2
1
0
-1
-2
-3
TANK DIA (FT)
0
10
12
14
16
18

Fig. 3-2

Fig. 3-2

3.2 EFFECTS OF TANK CONFIGURATION, FAIRING, AND POSITION

The effects of reshaping the nose and/or adding a forward fairing and also of relocating the tank on the orbiter were analyzed and reported in EM L2-12-01-M1-9 (see Appendix). This study shows that, from a strictly aerodynamic point of view, various alternatives to the initial configuration would result in considerable reductions of ascent drag. The primary points of interest are with regard to a fairing at the forward end of the tank or relocating the tank on the orbiter. Figure 3-3 shows the results of this study. Of the three bars shown, it appears that moving the aft end of the tank back toward the wing trailing edge is the most practical. Moving the tanks outboard involves considerable complication of the system along with probable weight increases. A fairing between the tank and the orbiter would be quite heavy and although it may alleviate the drag problem, the potential benefit with regard to TPS is less clear as indicated by the heat transfer tests in the LaRC variable density continuous flow hypersonic tunnel.

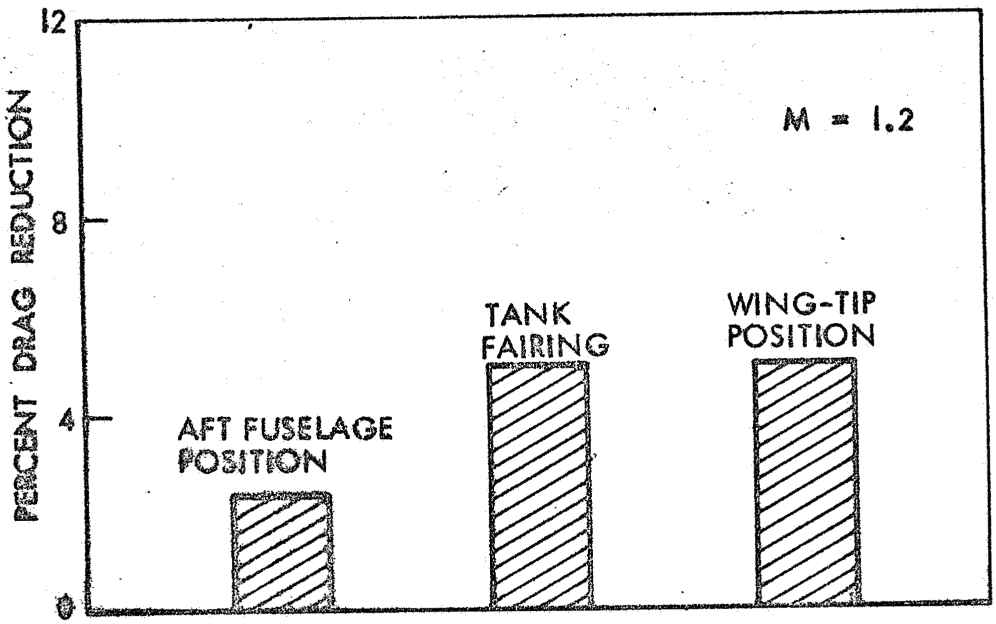


Fig. 3-3 Orbiter Ascent Drag Reduction Potential

Section 4
TANK ATTACHMENT AND SEPARATION ANALYSES

A parametric analysis of the droptank-orbiter separation was conducted and separation dynamics for different separation velocities established. Various attachment concepts were investigated and an evaluation of the primary candidate solutions performed.

4.1 SEPARATION ANALYSES

The separation analyses include the separation parametrics and separation/translation 6D simulations.

4.1.1 Separation Parametrics

The baseline mechanical separation system consists of two gas generators which operate separate pistons in the forward and aft attachment struts. The struts are physically separated from the orbiter, after which the gas generators are simultaneously ignited. The gas pressure forces the tanks away from the orbiter at a desired acceleration level. After physical separation is completed, the tanks are allowed to translate away from the orbiter to a predetermined distance, at which time the tank retrorocket is fired to expedite tank entry.

Parametric curves are provided in EM L2-12-02-M1-1 (see Appendix) for separation load factor, separation time, velocity at separation, translation distance, and angular deviations at separation.

4.1.2 Droptank Separation Histories

Definition of droptank separation histories is important to establishing deboost sequences with maximum assurance of orbiter safety. Furthermore, identification of body motion characteristics is necessary to provide inputs for reasonable prediction of droptank impact ranges and dispersion envelopes.

Translational separation histories were calculated for separation velocities (V_s) from 10 fps to 35 fps. The calculations assume coast periods before retro-fire and include effects of orbital/separation velocity relationships and droptank drag. The results show an insensitivity to drag effects indicating the validity of using the vacuum (ideal) distance equation, (distance = V_s x time) in separation analyses.

Histories of angular deviations from the droptank attitude at separation were calculated for two separation velocities: V_s = 10 fps and 35 fps. Assumed separation plane is 29.5 deg from the orbiter (tank) vertical reference axis. Angular $\Delta\theta/\Delta\psi$ (pitch/yaw) histories are essentially linear through coast (2 sec to 7 sec) and post-retro coast for all cases with a separation velocity of 35 fps. Only when pitch rate q' = 10 deg/sec does the relationship $\Delta\theta/\Delta\psi$ become nonlinear. Lowering separation velocity to 10 fps has little effect on angular deviations for the assumed pitch rates. These results again indicate insensitivity to drag as well as coupled angular rate/velocity effects.

Selection of a realistic pitch rate depends on the alignment and performance uncertainties of the separation devices. Analysis of an assumed gas generator piston device shows its performance is subject to large uncertainties. A reasonable estimate of these performance uncertainties indicates pitch rates of at least 5 deg/sec can be expected at separation. This angular rate was used in subsequent six degree-of-freedom body motion and trajectory studies.

A composite plot of intrack, crosstrack, vertical, and angular separation histories of the droptank relative to its initial position on the orbiter was generated for V_s = 35 fps, q' = 5 deg/sec (Fig. 4-1). For this case, the tank begins deboost at $\Delta\theta$ = -9 deg rotation to $\Delta\theta$ = -31 deg at burnout. Average pitch deviation for the retro period is -20 deg.

Separation for V_s = 10 fps was also analyzed. Of particular interest is the pitch and yaw deviation with respect to retro initiation. Since coast time must be extended to 10 sec to accommodate a minimum separation distance requirement (~70 ft), $\Delta\theta$ at retro initiation (10 sec) will be -44 deg.

Assuming a retro attitude, (θ_R), from zero to 40 deg maximum, the $\Delta\theta$ history will result in a rotation of the retro velocity vector such that it is directed up and aft (relative to the local horizontal and orbital direction respectively), with the result of increased time and range to impact. (The effect is further amplified by the added deviation in yaw.)

Further analysis is required to define these effects in detail, but suffice it to say at this time, increased ranges decrease the accuracy of impact predictions and dispersions, and are therefore undesirable. Consequently, it appears that higher separation velocities are required to offset large pitch rates. A separation velocity of 35 fps was assumed in all entry trajectory studies.

4.2 ATTACHMENT/SEPARATION CONCEPTS

The employment of a set of external LH_2 droptanks on a typical orbiter system requires the investigation of means for supporting as well as methods for separating and deploying the tank systems. The following set of design drawings illustrate the various concepts associated with this aspect.

An initial approach to the support, separation and deployment of each LH_2 tank system was characterized by the Grumman concept as furnished by NASA. The drawings shown in this section are additional concepts starting from a modified approach to the Grumman concept to arrangements that vary from a fully reusable type to basically a throwaway system.

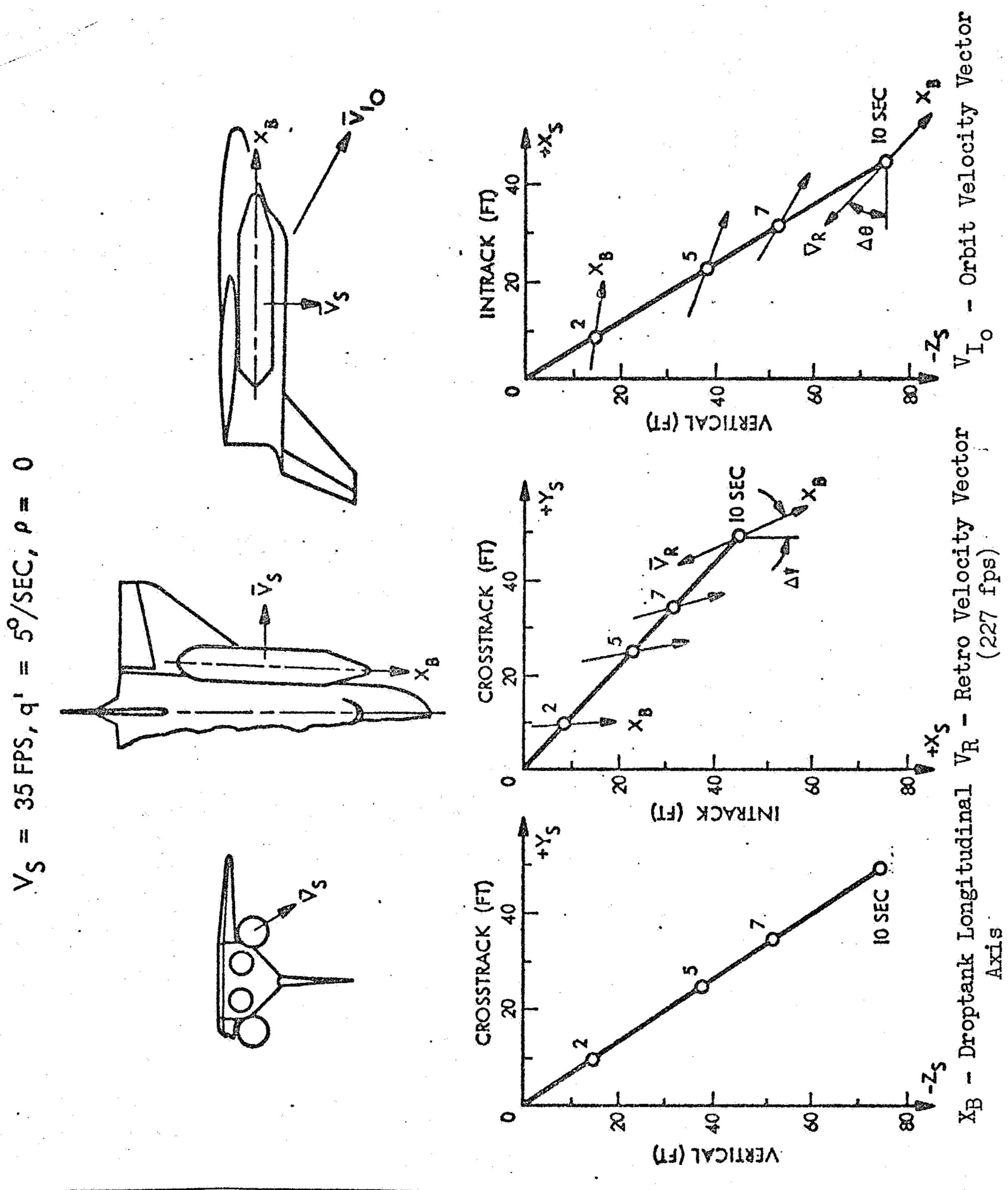


Fig. 4-1 Component Distances Separating Droptank From Orbiter

Fig. 4-1

Design Drawing SKG 100706 (Fig. 4-2), illustrates several separation and attachment schemes based upon the Grumman and modified Grumman attach concept. The arrangement shown in the upper right-hand corner shows an alternate approach to the Grumman V-clamp strut/orbiter separation system where three clamps/explosive bolts per strut for a five (5) strut system are used. The alternate shown reduces the number of explosive devices to one per strut. The pyrotechnics used are assumed to be accessible from within the orbiter. Deployment actuators are still employed and mounted within the lower forward and aft struts as per Grumman concept. After separation of the struts from the orbiter, the severed bolt fitting is relatively small in diameter and together with the mass of squib material plus enclosed mounting bracket located behind the heat shield, eliminate any flow of high-temperature air through the heat shield. The tank separation system alternate configuration geometry shown in the bottom of the drawing is a modification to the Grumman concept. In this approach, four (4) compression struts, one (1) drag strut, and two (2) tension rods are used per tank side. This arrangement provides for only two attach points (Detail B) per tank with all the compression struts located in orbiter-mounted sockets (Details A and C). Tank deployment actuators are again located in the forward and aft lower compression struts. The tension rod separation concept (Detail B) is similar to that already described.

Alternate Detail B uses a tension strut in place of a tension rod so that the deployment actuator can be incorporated within this strut. In this arrangement, all pyrotechnic devices are essentially located at one place (two per tank) and assumed accessible from inside the orbiter. No holes are required in the heat shield. If necessary, a potential mechanical backup separation system can more easily be provided. The geometry of the strut system in this case is such that deployment of the tanks is in a 30-deg direction with respect to an orbiter waterline (normal to the Grumman orbiter fuselage surface).

Design Drawing SKG 100712 (Figure 4-3) illustrates some of the candidate tank support concepts considered and which represented the spread of approaches between a throwaway system (shown on left) and a basically fully reusable system (shown on right). Details of each of these approaches were drawn for weight estimation purposes and are shown in Design Drawings SKG 100714 (Figure 4-4) for the retractable system and in Design Drawing SKG 100716 (Figure 4-5) for the throwaway system. The estimated weights of these systems as compared to the estimated weight of the basic Grumman strut system are as follows:

- Grumman Concept 259 lb
- Retractable Concept 400 lb
- Throwaway Concept 93 lb

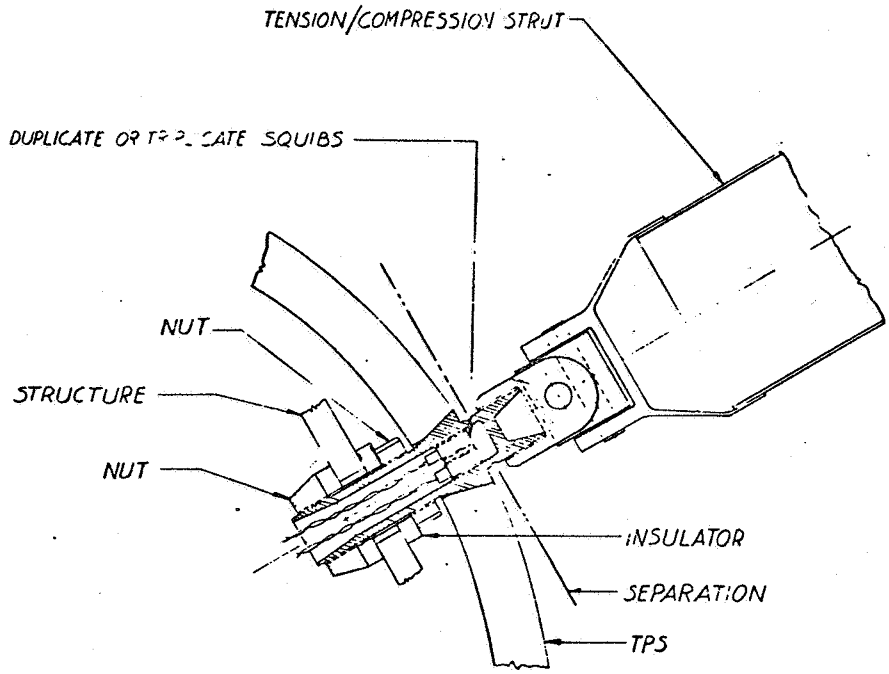
(See Section 10.2.3 for complete structure and weight analysis.)

4.3 ATTACHMENT/SEPARATION METHOD COMPARISONS

A system analysis of the attach/separation designs described in the preceding sections was performed to determine and evaluate the program cost impacts produced by the methods proposed. Figure 4-6 shows the design candidates analyzed. Three expendable link designs and one reusable cylinder design were investigated:

- Configuration I - 2 tubes forward and 3 tubes aft;
- Configuration II - 2 rods and 1 tube forward and 3 rods and 1 tube aft;
- Configuration III - 2 rods and 1 tube forward and 2 rods and 1 tube aft;
- retractable cylinder - telescoping cantilevered rod and cylinder built into the orbiter vehicle.

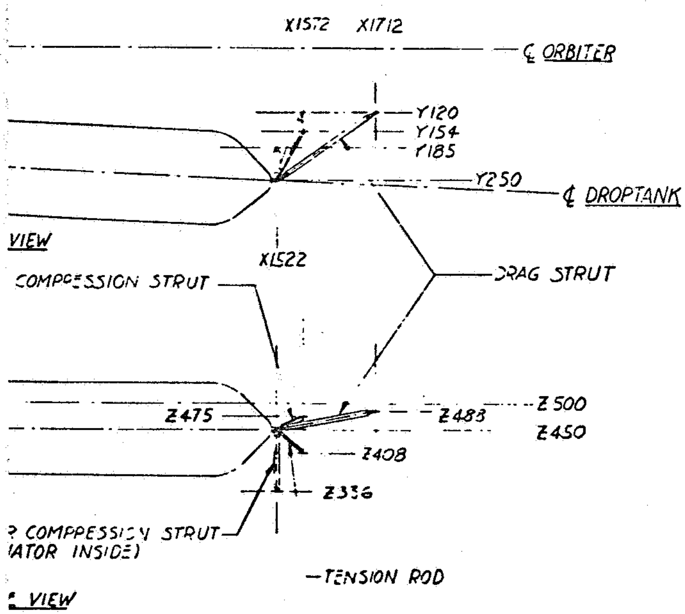
The tradeoff analysis was performed to both evaluate the four described design configurations and to determine the desirability of either retaining the subsystem or expending it along with the droptank. Table 4-1 presents the results of these tradeoff studies. For all configurations analyzed, the lightest weight design is the most cost effective. The lightest weight system is Configuration III. When comparing Configuration III, which is an expendable link design, to the reusable cylinder design, the reusable design shows a slight cost penalty to the program of approximately $1 million. This higher cost associated with a reusable system stems from the maintenance costs and higher weight and complexity of a system which must be built into the orbiter, thereby offsetting any cost savings of smaller production quantities.



ALTERNATE FOR GRUMMAN V-CLAMP SEPARATION SYSTEM - 5 PER TANK

½ SIZE

(ACTUATORS INSIDE STRUT - 2 PER TANK)



EM ALTERNATE CONFIGURATION

1/100 SIZE

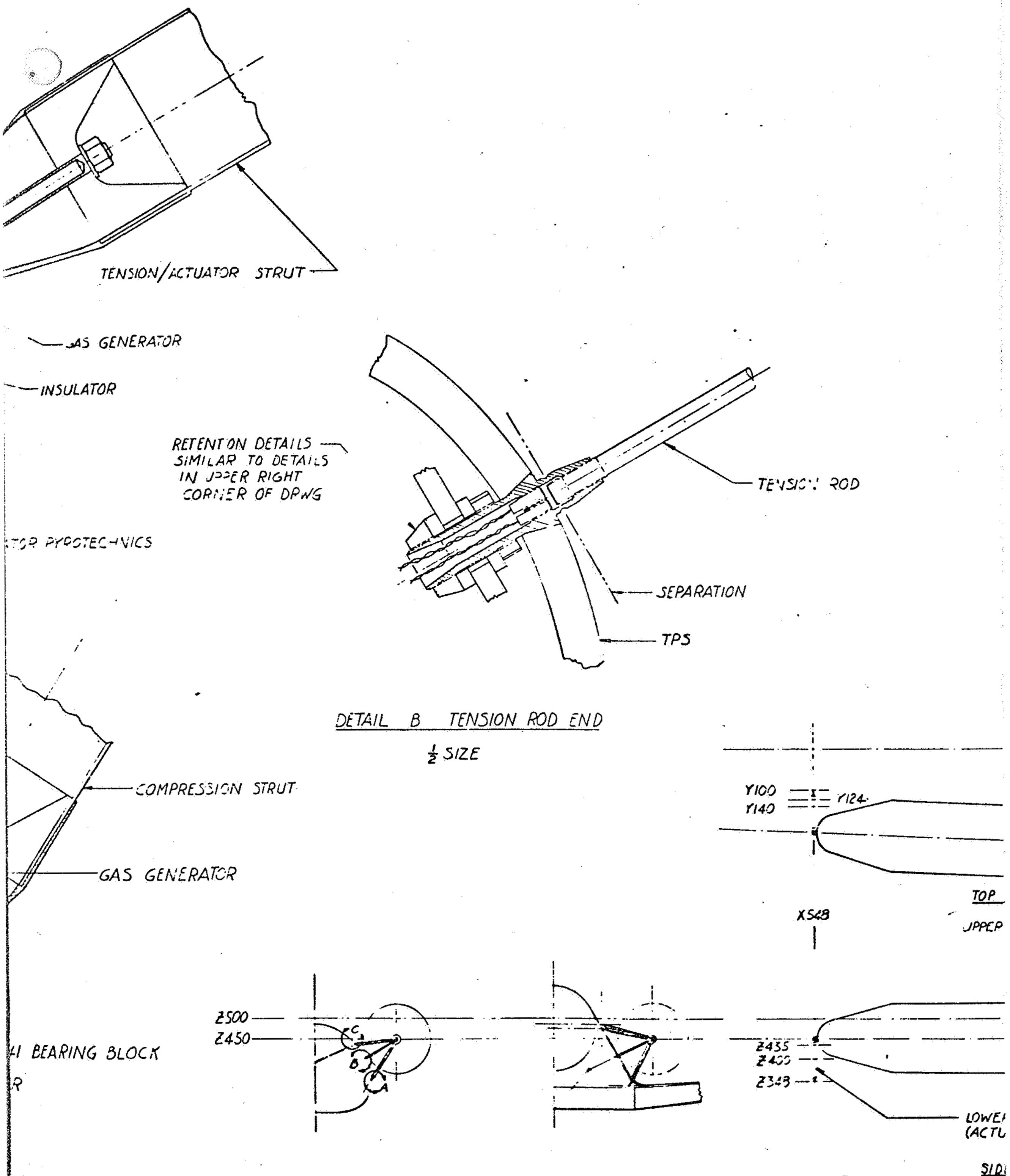
LOCKHEED MISSILES & SPACE COMPANY
SUNNYVALE, CALIFORNIA

DATE | DR | APPD | APPD | ENGRG | CHK | APPD | APPD

SIZE | CODE IDENT | DRAWING NO | REV

SCALE | SHEET

Fig. 4-2 Separation and Attachment Schemes



DETAIL B TENSION ROD END

½ SIZE

ACTUATOR STRUT END

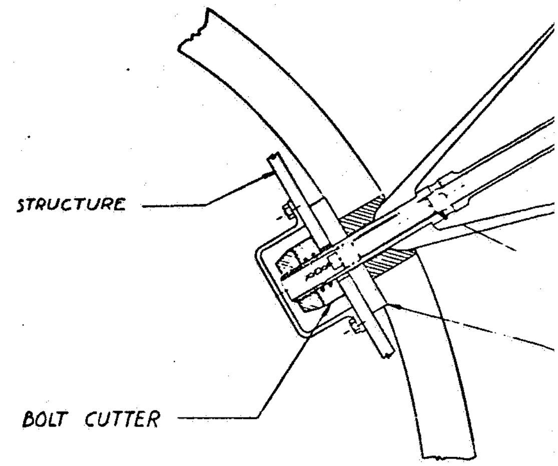
½ SIZE

SIMILAR EXCEPT OMIT GAS GENERATOR

X548

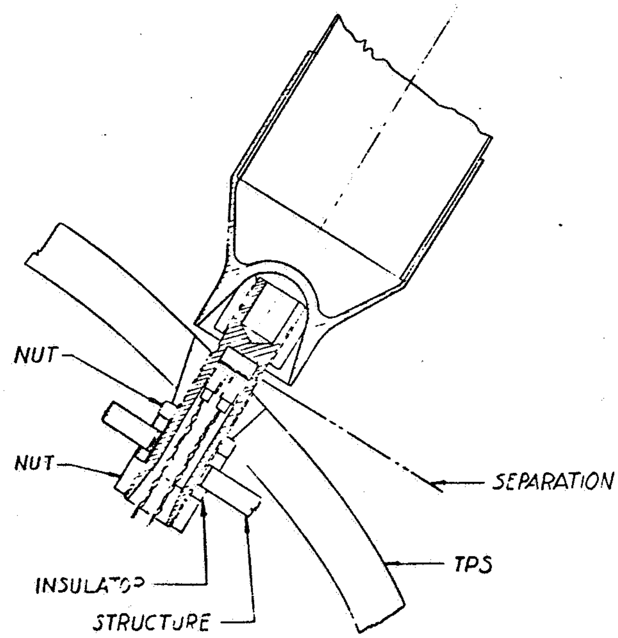
X1522

TANK SEPARATION SYST

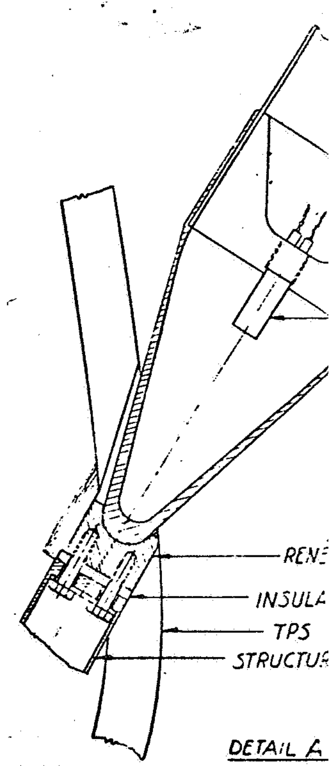


ALTERNATE DETAIL

INTEGRATED SEPARATION & AC

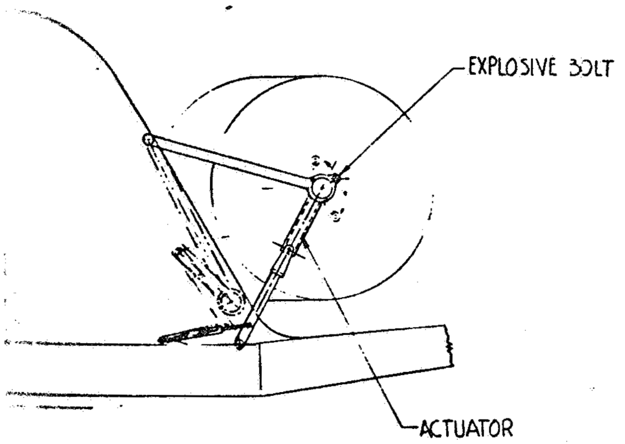


ALTERNATE DETAIL A/C

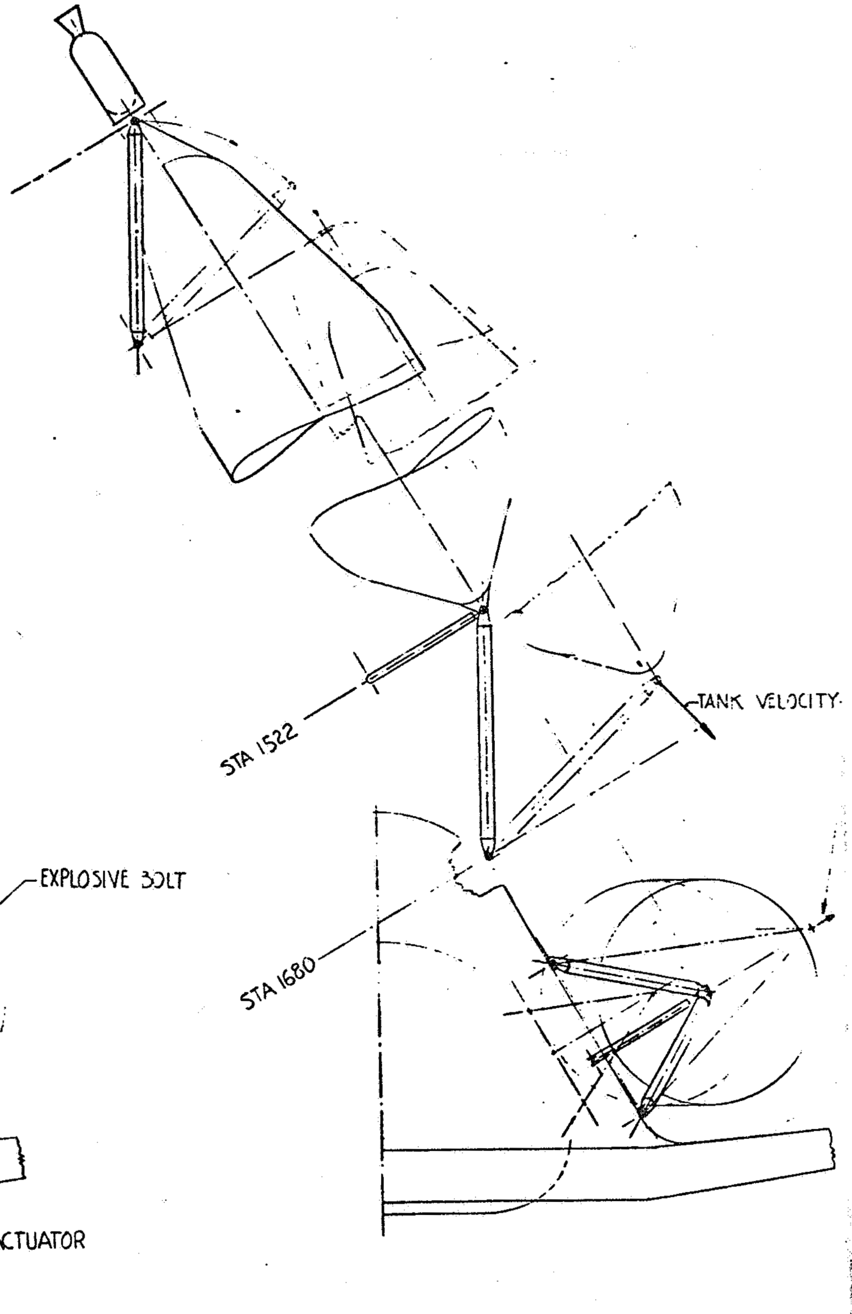


DETAIL A

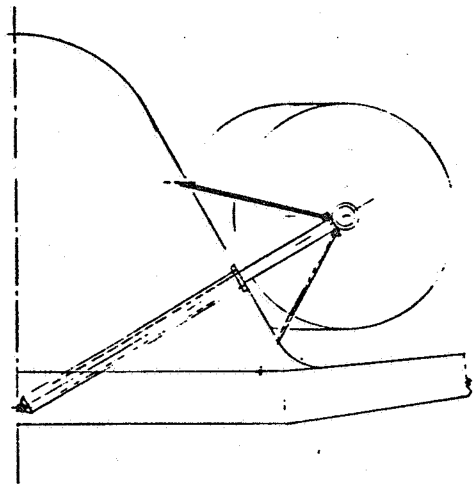
DETAIL C



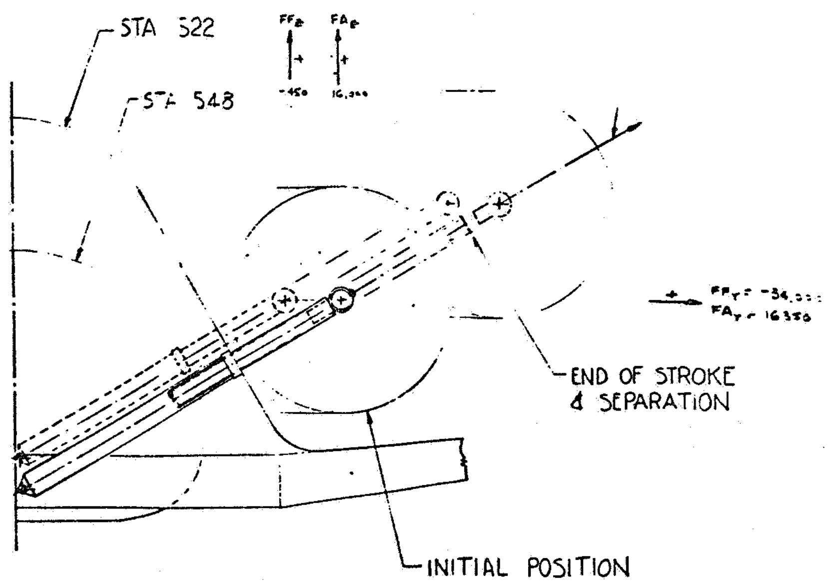
RETRACTABLE STRUTS



PARALLEL LINKAGE



WIRE-BRACED PISTON



CANTILEVER PISTON SUPPORT & EJECTION

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

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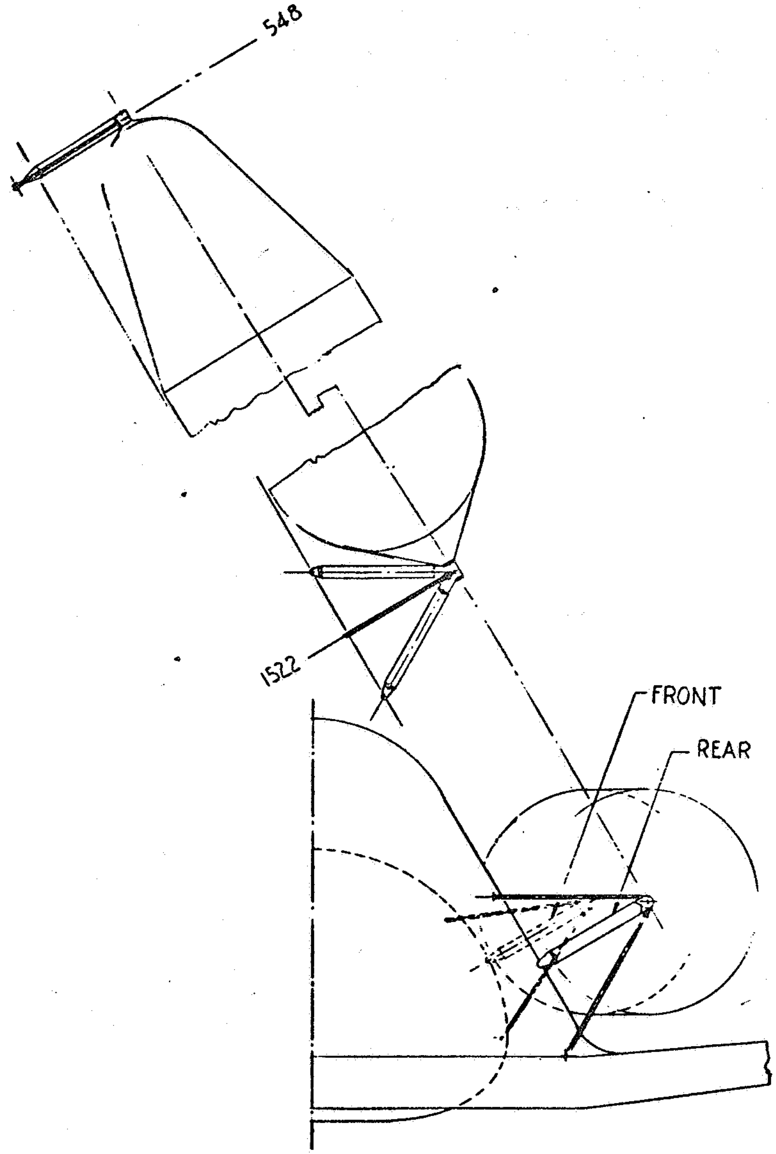
Fig. 4-3 Candidate Tank Support Concepts



THROW AWAY SYSTEM

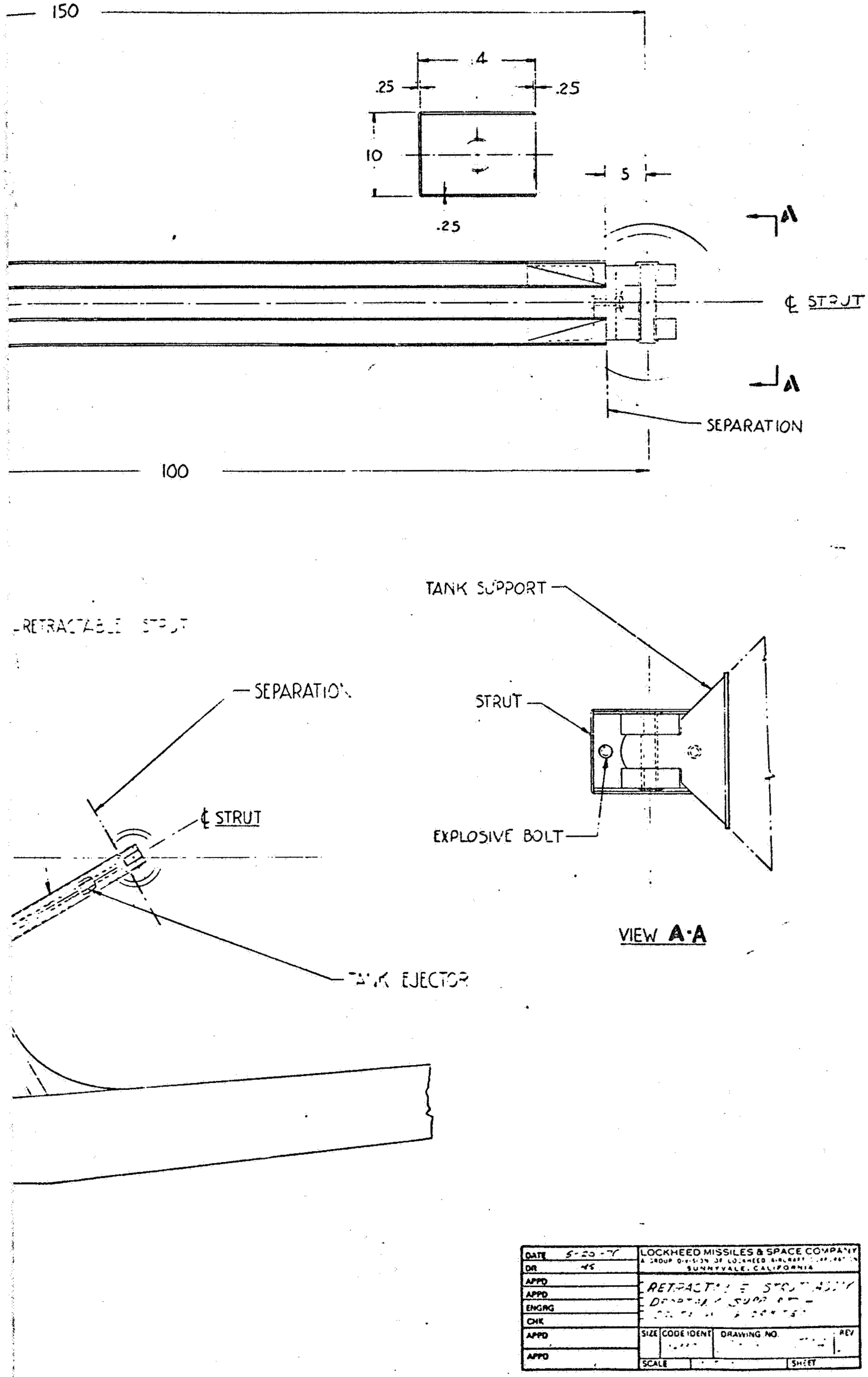
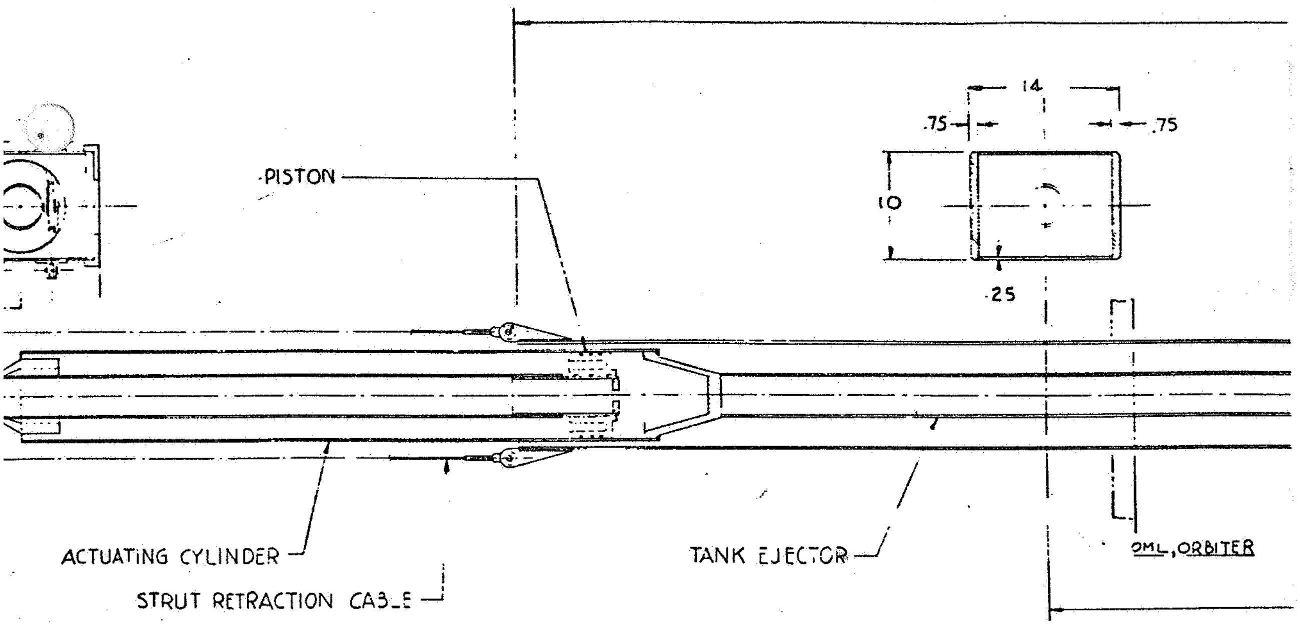
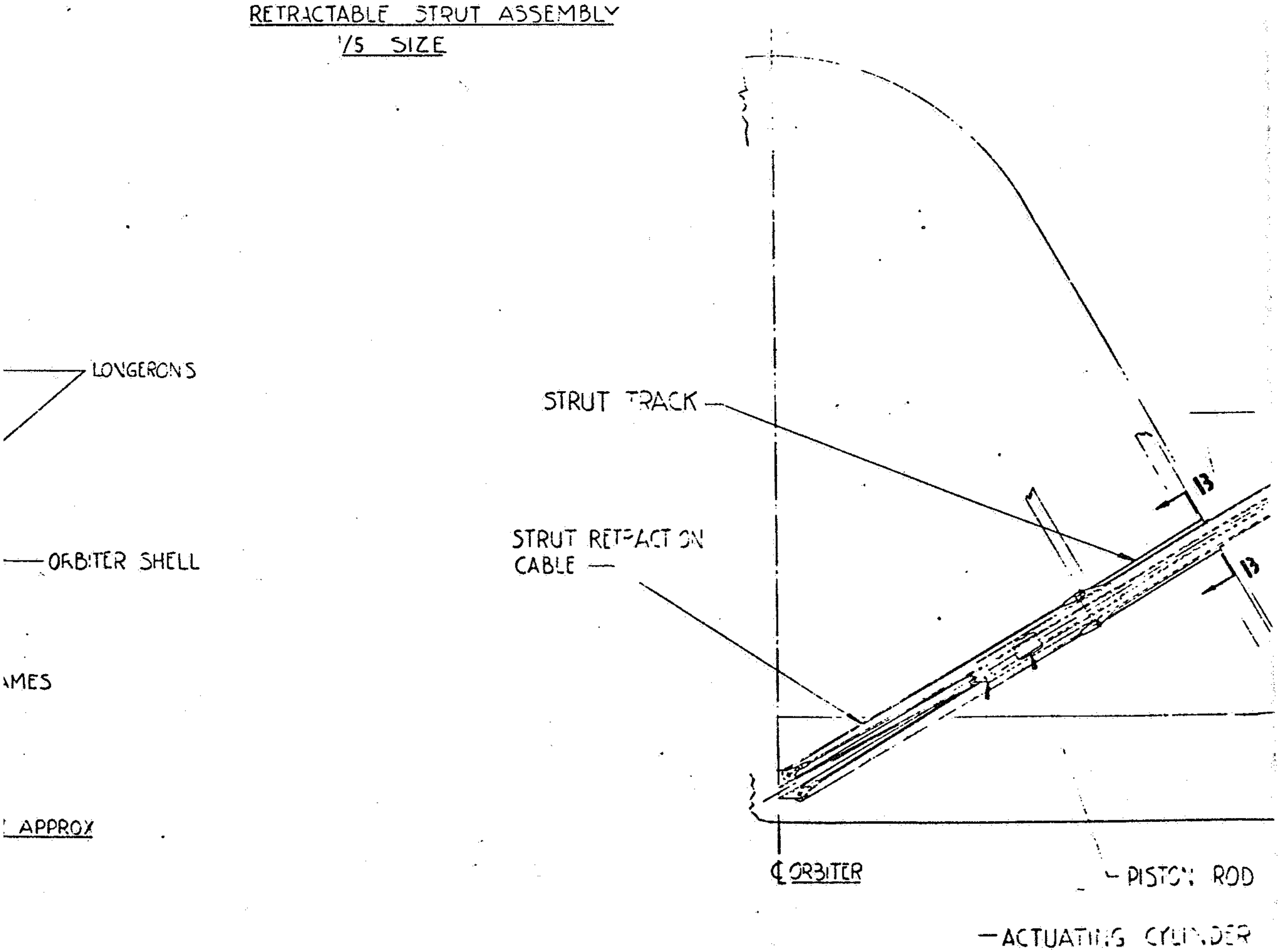


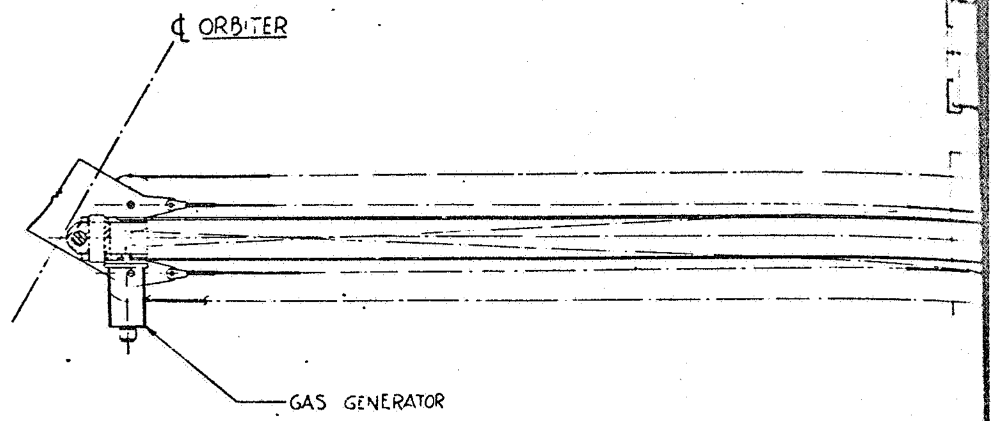
Fig. 4-4 Retractable Strut Assembly

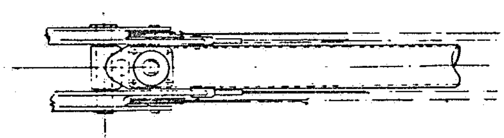


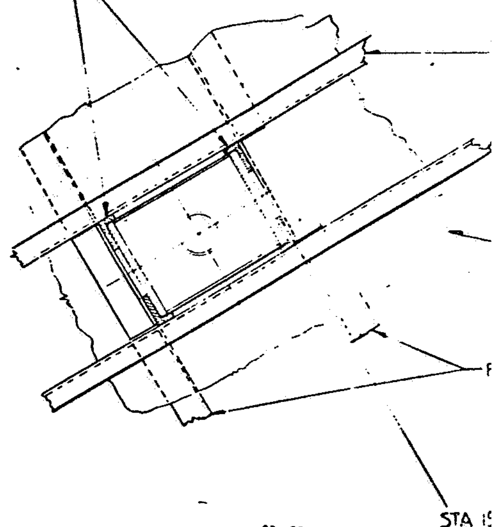
RETRACTABLE STRUT ASSEMBLY
1/5 SIZE



REAR VIEW, R.H. TANK
1/20 SIZE







SECTION B-B
1/5 SIZE

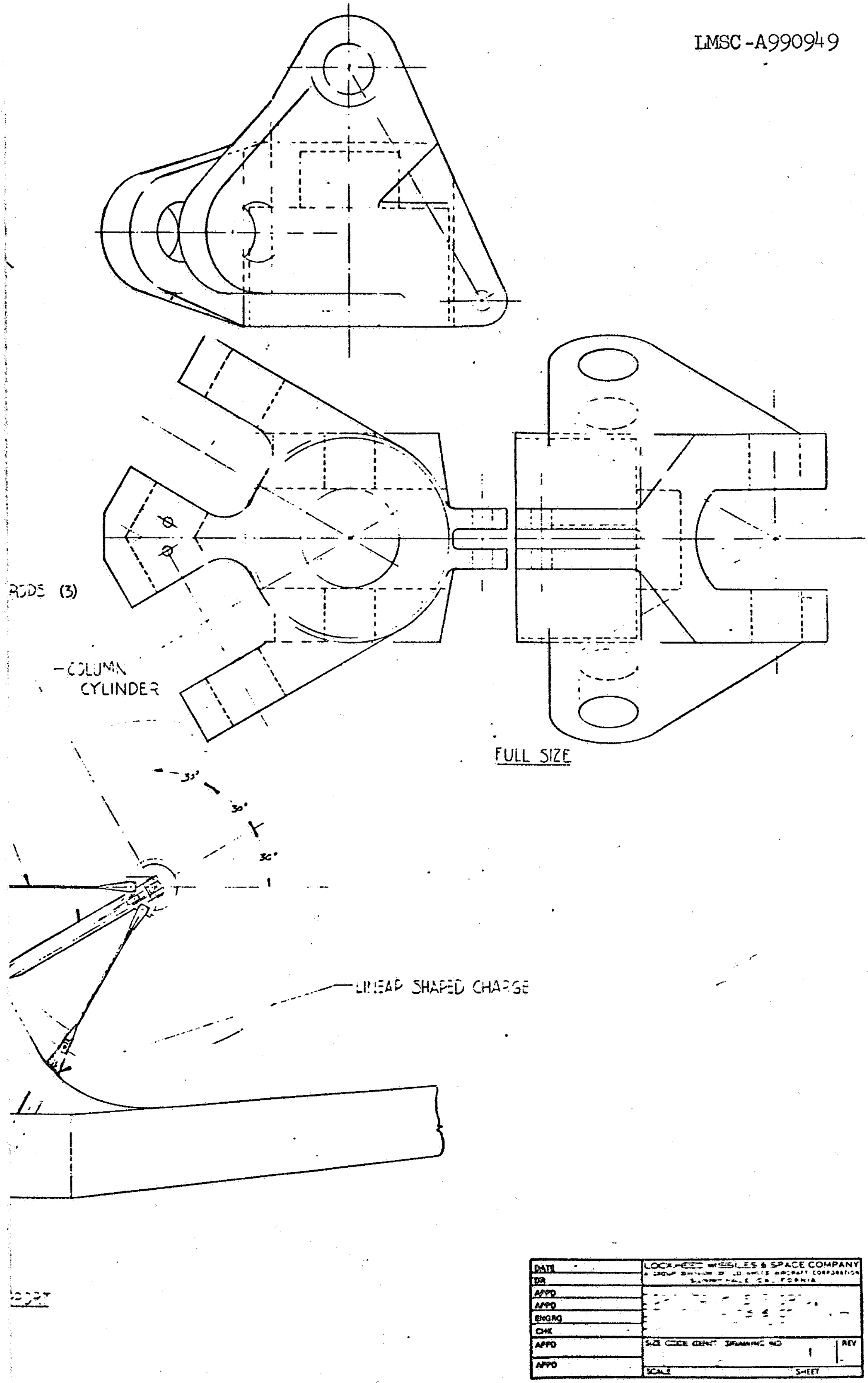
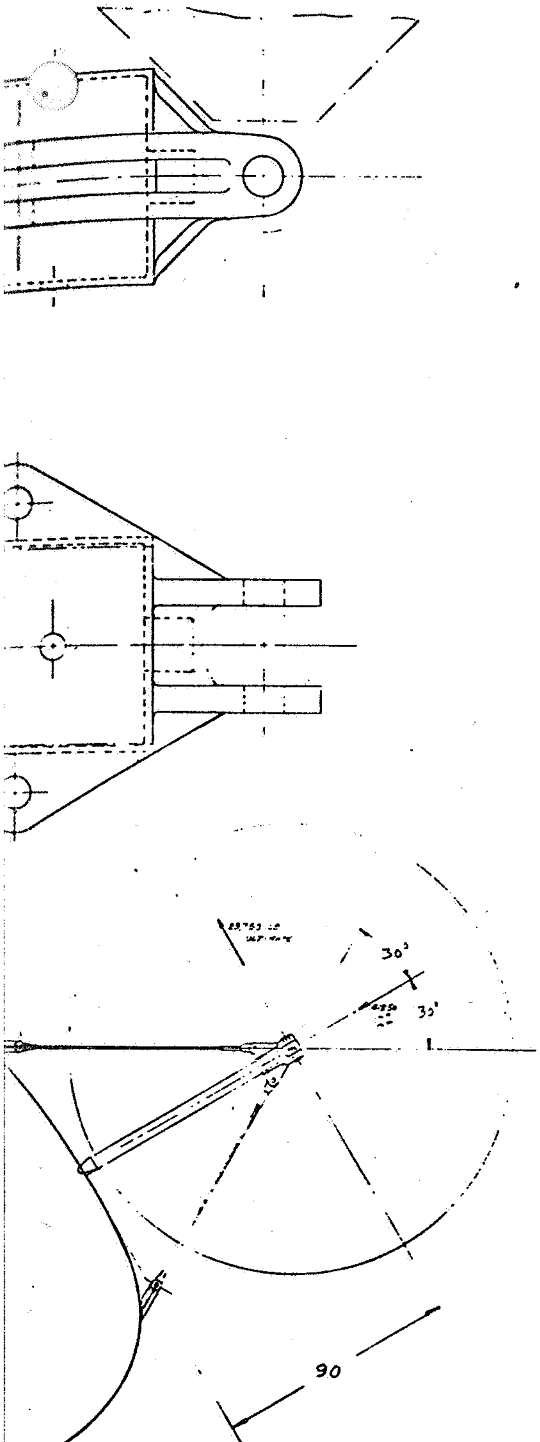
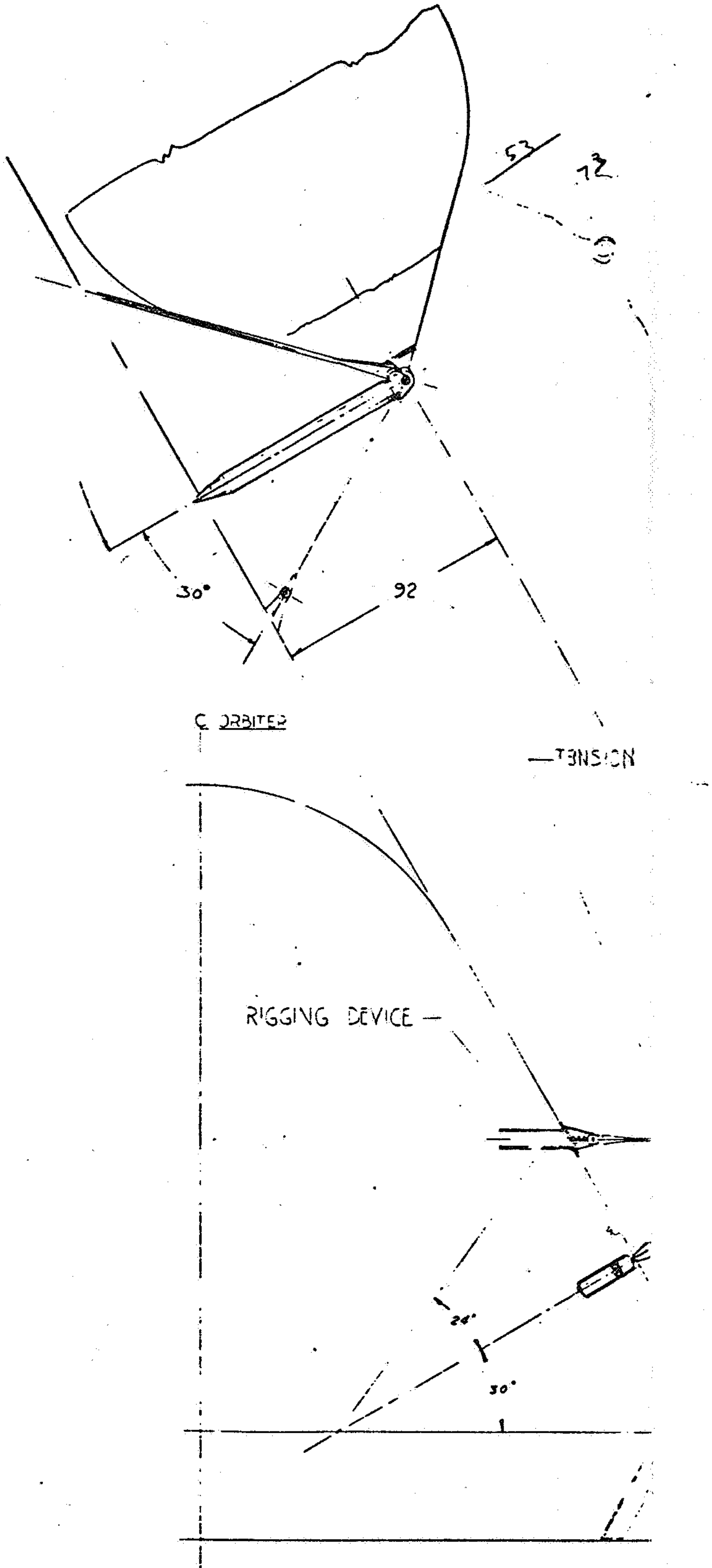


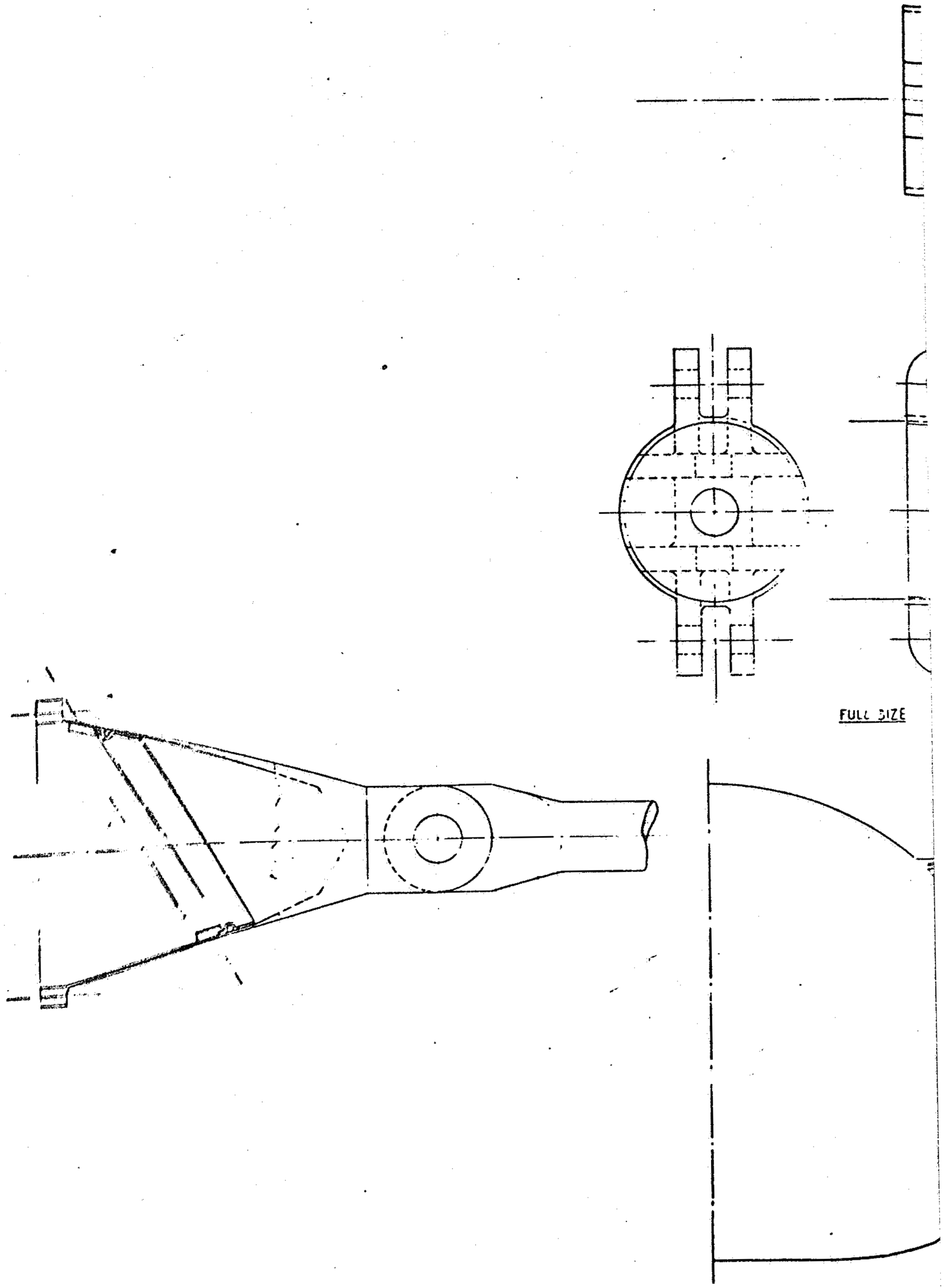
Fig. 4-5 Throwaway System



FRONT SUPPORT, R.H. TANK
1/20



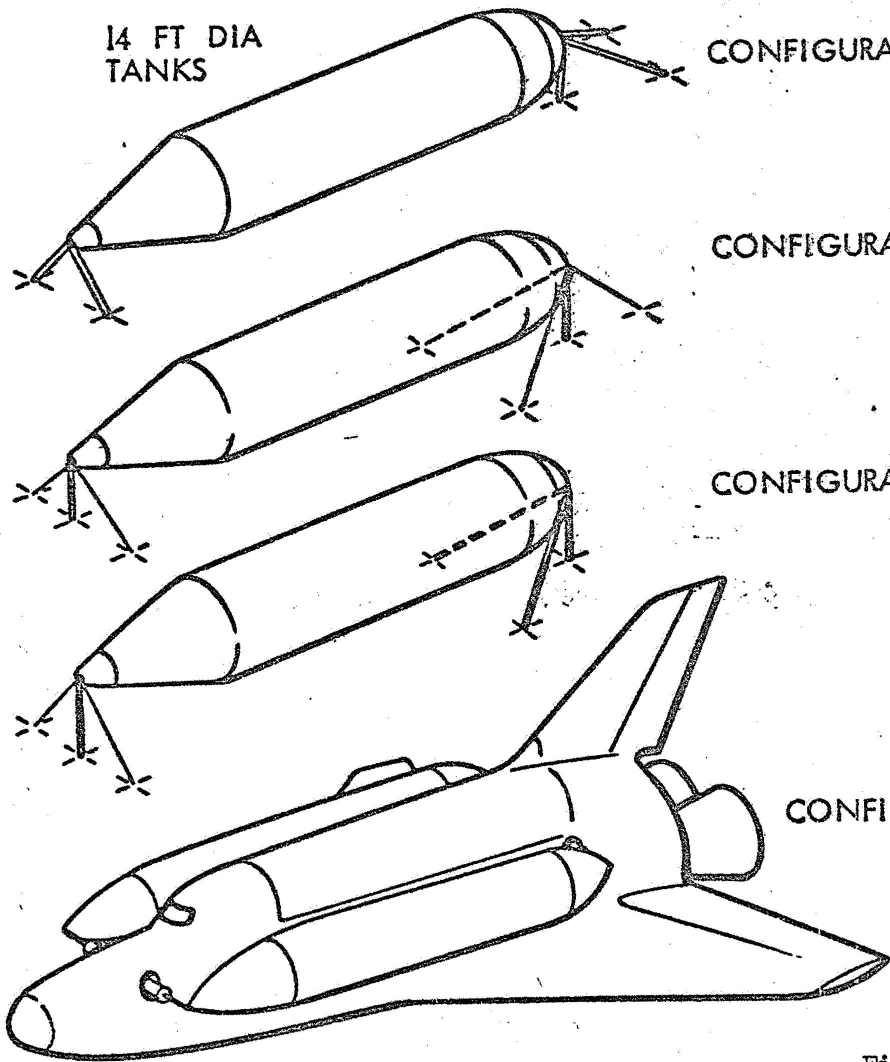
REAR VIEW, R.H. TANK SU
1/20


FULL SIZE

LOCKHEED

DROPTANK SUPPORT CONFIGURATIONS

14 FT DIA TANKS



CONFIGURATION 1 — ALL TUBULAR MEMBERS, WEIGHT = 259 LB

CONFIGURATION 2 — TWO TUBES AND FIVE RODS, WEIGHT = 118 LB

CONFIGURATION 3 — FOUR TUBES AND TWO RODS, WEIGHT = 93 LB

CONFIGURATION 4 — TELESCOPING CYLINDER, WEIGHT = 400 LB

Fig. 4-6

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Fig. 4-6

Table 4-1

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ATTACH/SEPARATION METHOD TRADEOFF STUDY

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	TYPE OF SUBSYSTEM FOR 14 FT DIA ALUMINUM TANK			
	EXPENDABLE SIMPLE LINK			REUSABLE CYLINDER
	CONFIG. 1	CONFIG. 2	CONFIG. 3	
* ATTACH/SEPARATION SUBSYSTEM WEIGHTS	(518 LB) $ 2.7	(236 LB) $ 0.4	(186 LB) REF WT	(800 LB) $ 4.9
PRODUCTION COST	$ 6.4	$ 7.6	$ 7.4	$ 0.4
MAINTENANCE COST	$ 0	$ 0	$ 0	$ 2.8
COMPARISON TOTAL	$ 9.1	$ 8.0	$ 7.4	$ 8.1
RELATIVE COST	$+1.7	$+0.6	REF	$+0.7

* DROPTANK WEIGHT SENSITIVITY = $8,000/LB

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Table 4-1

Section 5
TANK DEORBIT AND ENTRY ANALYSES

Retrorocket parametric curves were calculated and a survey of applicable hardware was conducted. The bulk of the effort centered on the 3D and 6D separation, deorbit, entry and dispersion simulations.

5.1 RETROROCKET PARAMETRICS

The retrorocket parametrics are reported in EM L2-12-01-M1-11 (see Appendix). Data are provided for velocity requirements ranging from zero to 300 fps based on a tank weighing 10,300 pounds. Tanks of different weight can be accommodated by proportioning the ΔV requirement and the weight. Parametric curves which relate propellant to ΔV; thrust to throat diameter; rocket length to throat diameter; and impulse deviation to ΔV are provided.

5.2 SOLID PROPELLANT ROCKET SURVEY

A survey of existing solid propellant rocket hardware was conducted to determine the applicability of such rockets to the retro requirements. Table 5-1 shows the possibilities which are in the impulse range of interest.

The table shows that the last two motors could be used as retrorockets, but even for these the impluse-to-weight ratio is not especially good. The ratio should be more of the order of 250 or 270 for this application. These two existing retrorocket motor candidates are compared with two new motor candidates in Section 5.6, and this comparison indicates that it would probably be desirable to develop a new motor for this shuttle application.

Table 5-1

DEVELOPED ROCKET HARDWARE

	Rocket Designation		Company*	Dia/Length Dimensions (in.)	Temperature Limits (°F)	Rocket Vacuum Impulse-to-Weight Ratio (Lb-sec/Lb)	ΔV Per 10K Tank (fps)
1.	7.3KS	5,357	TCC	7.8 x 104.4	-40/+150	156	138
2.	2.5KS	11,000	AGC	13.6 x 70.4	+40/+100	61	98
3.	3 KS	18,900	AGC	12.0 x 58.6	-65/+180	194	201
4.	2.4KS	24,400	LPC	9.0 x 100.3	+30/+130	183	208
5.	8.3KS	30,800	TCC	15.0 x 67.0	-75/+175	130	197
6.	8.3KS	10,966	TCC	9.0 x 142.2	-10/+130	208	324

* TCC = Thiokol; AGC = Aerojet; LPC = Lockheed Propulsion Company

5.3 RETROROCKET INSTALLATION CONCEPTS

The baseline tank system had the retrorocket in the nose with a fairing protection. For this installation the nose cap must be jettisoned, exposing the nozzle exit for retro fire. This concept is acceptable when a tumbling entry is anticipated because the exposed TPS section between the nozzle and the fairing will be subjected to the same amount of heating regardless of the fore or aft location of the rocket, with a design advantage for the latter. However, when confronted with the problem of a trimmed entry, it appears prudent to reconsider and possibly install the retrorocket at the aft end. Whether discussing tumbling or trimmed entry, the tank rotational rates during retro firing are small.

5.3.1 Rocket Installation For Tumbling Intact Entry

There are basically four considerations when discussing the proper location of the rocket: (1) orbiter maneuver requirements, (2) installation feasibility, (3) entry stability, and (4) intact entry protection. These items are qualitatively evaluated in Table 5-2.

Table 5-2

ASPECTS OF RETROROCKET LOCATION FOR INTACT TUMBLING ENTRY

	Rocket FWD	Rocket AFT	Comment
1. Orbiter maneuver requirement	$\pm 180^{\circ}$ Roll $\pm 37^{\circ}$ Pitch	$\pm 127^{\circ}$ Pitch	Advantage for fwd location
2. Installation feasibility	Must jettison nose cap	Equivalent to burst diaphragm	Advantage for aft location
3. Tank entry stability problem	Most fwd C.G. (stabilizing)	Most aft C.G. (destabilizing)	Advantage for aft location
4. Intact entry thermal protection	Nozzle exit-firing interface at nose cap separation plane is exposed	No separation at nozzle exit - TPS interface required	Advantage for aft location

This tabulation indicates an advantage for the aft location when considering tumbling only. The decision may depend on an orbiter operations analysis which would show the penalty comparison involved for achieving the required attitudes for tank separation prior to retro fire.

5.3.2 Rocket Installation For Trimmed Intact Entry

The foregoing system considerations are again itemized in Table 5-3 to express a qualitative comparison when trimmed entry is anticipated.

This comparison shows that neither location indicates a strong advantage. However, because the present knowledge of the effects of the entry aero-thermal environment on the forward exposed retrorocket nozzle/insulation interface is incomplete, an aft location is represented as preferred.

5.4 ENTRY TRAJECTORIES AND FLIGHT DYNAMICS

Droptank entry trajectories and flight dynamics were investigated to ascertain nominal trajectory profiles to specific impact areas; body motion during entry, and range sensitivities to orbital, retro, and body parameter deviations. Typical range dispersions for a maximum range trajectory were calculated and fragment impact patterns for an assumed structural failure during entry were defined. Detailed results are reported in EM L2-12-05-M1-8 (see Appendix).

5.4.1 Given and Assumed Conditions

Both three degree-of-freedom (3D) point mass and six degree-of-freedom (6D) trajectory simulations were generated assuming initial conditions on each of the four orbits* in Section 2.2.1. An oblate, rotating earth model and the 1962

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* Orbit 1, I = 28.5 deg; Orbit 2, I = 55 deg; Orbit 3, I = 90 deg ETR(S); Orbit 4, I = 90 deg WTR(S)

Table 5-3

ASPECTS OF RETROROCKET LOCATION FOR INTACT TRIMMED ENTRY

	Rocket FWD	Rocket AFT	Comment
1. Orbiter maneuver requirement	$\pm 180^{\circ}$ Roll $\pm 37^{\circ}$ Pitch	$\pm 127^{\circ}$ Pitch	Advantage for fwd location
2. Installation feasibility	Must jettison nose cap	Equivalent to burst diaphragm	Advantage for aft location
3. Tank entry trim-stability problem	Most fwd C.G. (stabilizing)	Most aft C.G. (destabilizing)	Advantage for fwd location
4. Intact entry thermal protection	Nozzle exit-firing interface at nose cap separation plane is exposed	No separation at nozzle exit - TPS interface required	Advantage for aft location

U.S. Standard Atmosphere modified to include solar activity effects on density* were used.

Droptank mass properties are established in EM L2-12-M1-1 and nominal retrorocket characteristics in Section 5.1 and EM L2-12-01-M1-11 (see Appendix). Aerodynamic data were determined over an angle-of-attack range from 0 to 180 deg for use in the 6D studies using an arbitrary body aero-characteristics computer program**. Point mass trajectories assumed tumbling and minimum drag characteristics to bound possible entry profiles.

The assumed flight sequence includes inverting the orbiter (roll 180 deg) and pitching up to a predetermined retro pitch angle (θ_R) before tank separation, (Fig. 5-1). Separation is accomplished using a gas generator system followed by a tank coast period sufficiently long to ensure a distance of at least one tank length from the orbiter; then retrofire occurs.

5.4.2 Parametric Retro/Range Analysis

Since minimum range generally results in minimum dispersions for ballistic entry trajectories, initial phases of the 3D analysis are concerned with ascertaining relationships of retro pitch angle (θ_R) to entry range for the nominal retro-rocket configuration (retro velocity, V_R = 227 fps). Furthermore, since a specific impact location is desired (Indian Ocean), the effects on range and impact location of time delays from perigee injection to retrofire are also of importance.

* S. K. Lew: Influence of Solar Activity on Atmospheric Density and its Impact on Space Design, LMSC/D006304, (TM 62-12-002), Lockheed Missiles & Space Co., Sunnyvale, Ca., 9 January 1970.

** A. F. Gentry: Hypersonic Arbitrary Body Aerodynamic Computer Program (Mark III Version), DAC 61552, Douglas Aircraft Co., April 1968.

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ORBITER/DROPTANK ORIENTATION AT SEPARATION

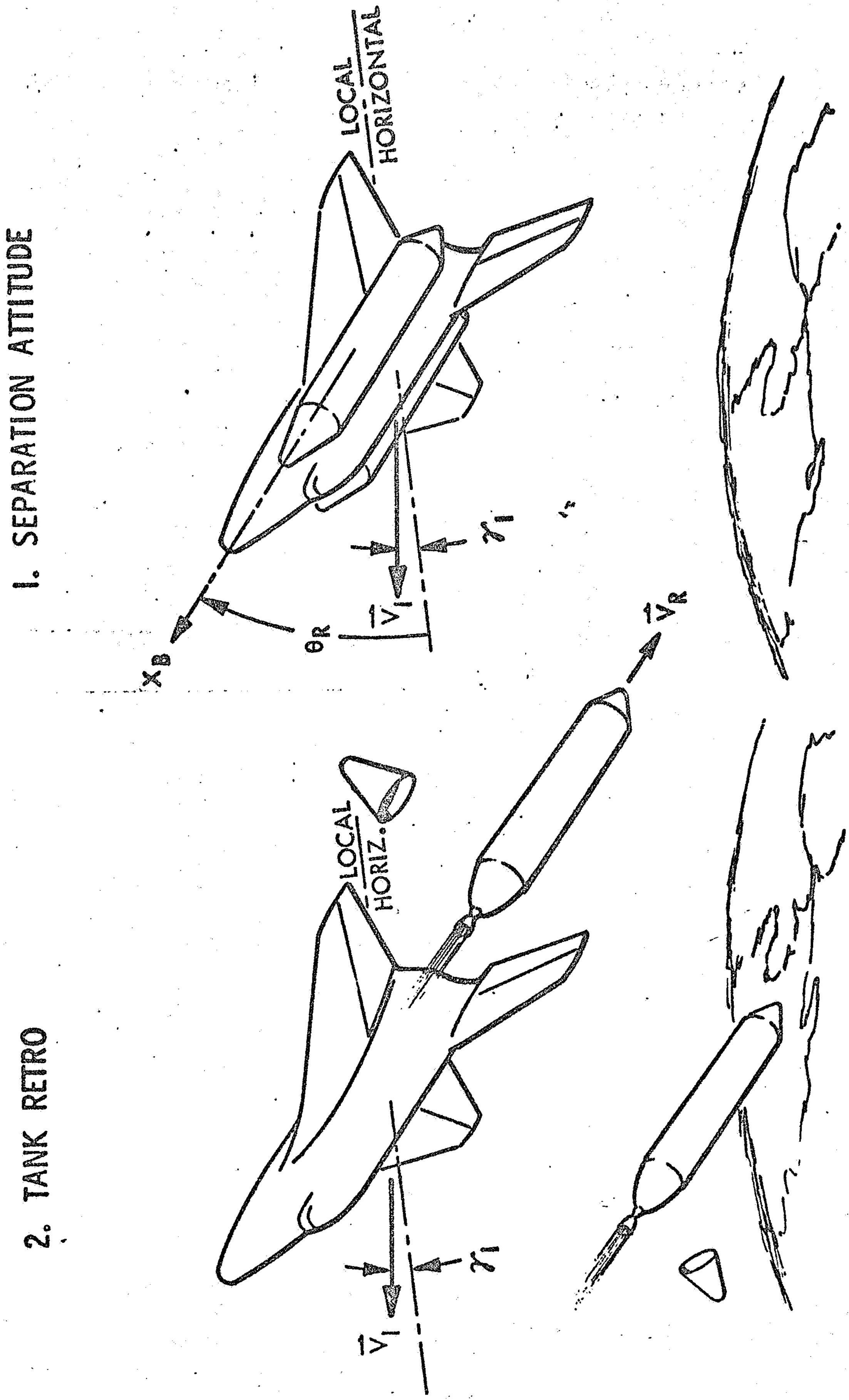

Fig. 5-1

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Fig. 5-1

Variations in range from deboost to impact* from the four reference orbits and for various retro times (from perigee) were determined. Tumbling drag conditions were assumed. Range increases with retro initiation time reflecting differences in initial conditions at retro. Retro pitch angle for minimum range, $(\theta_R)_{opt}$, is about 75 deg, decreasing to about 30 deg when retro occurs 25 min after perigee injection. The comparative effect of reducing the drag profile is to increase entry range and $(\theta_R)_{opt}$. Indian Ocean impact requirements were assumed.

Retro pitch angle is generally selected to minimize entry range. Since the orbiter must assume the desired attitude for retro, however, range alone cannot be the only criterion. Large pitch angles increase orbiter drag thereby increasing mission energy (velocity) requirements. Consequently, selected retro pitch angles for nominal trajectory simulations were limited to $\theta_R < 40$ deg. These angles are listed in Table 5-4 and are used for all entry simulations from each of the orbits indicated.**

Table 5-4

SELECTED RETRO PITCH ANGLES

Orbit 1	θ_R = 37 deg
Orbit 2	θ_R = 39.5 deg
Orbit 3	θ_R = 32.4 deg
Orbit 4	θ_R = 33.5 deg

5.4.3 Nominal Point Mass Trajectories

Nominal entry trajectories were generated for Indian Ocean impact assuming both tumbling and minimum drag entry conditions. Impact coordinates are at

* Impact altitude is at 50,000 ft.

** The θ_R magnitudes in Table 5-4 were not optimized for orbiter on-orbit performance. They probably do, however, represent near tolerable maximums for the system.

about 28.5 deg S latitude and longitudes between 80 deg E and 90 deg E except for polar launches from WTR (orbit 4) which has an assumed impact at 45 deg S, 49 deg E. Entry ranges are about 4900 nm for tumbling drag conditions and 5500 nm for minimum drag trajectories.

Entry range differences between each of the four reference orbits are a maximum of about 300 nm regardless of the comparative entry profiles. Flight times are within 2 minutes for all tumbling drag or all minimum drag profiles and comparisons of peak dynamic pressure, $(\bar{Q})_{max}$, and peak laminar stagnation point heat rate, $(\dot{Q}_s)_{max}$, also show only small influences. Comparison of tumbling and minimum drag entry from a given orbit to an Indian Ocean impact show greater differences, however (except for flight times). Ranges vary to about 600 nm, $(\bar{Q})_{max}$ changes by an order of magnitude, and $(\dot{Q}_s)_{max}$ differs by at least a factor of 3.

Perigee-retro trajectories exhibit comparable similarities, but flight times and ranges are considerably shorter reflecting lower altitude-higher drag conditions at retro.

Droptank decay trajectories (i.e., $V_R = 0$) from perigee were also investigated to determine the necessity of using a retrorocket . In all cases droptank entry is possible. But, only tumbling entry from 28.5 deg missions out of ETR and polar missions launched southerly from WTR is practical from a range safety standpoint.

Figure 5-2 shows a summary of impact locations for various deorbit conditions including increased retro velocity.

5.4.4 6D Entry Trajectory Analysis

Six degree-of-freedom entry simulations define dynamic flight characteristics of an LH_2 droptank over its entire descent trajectory. The analysis also parametrically investigates the effects of changes in center-of-gravity location, thrust misalignments, and tumble rates on flight characteristics.

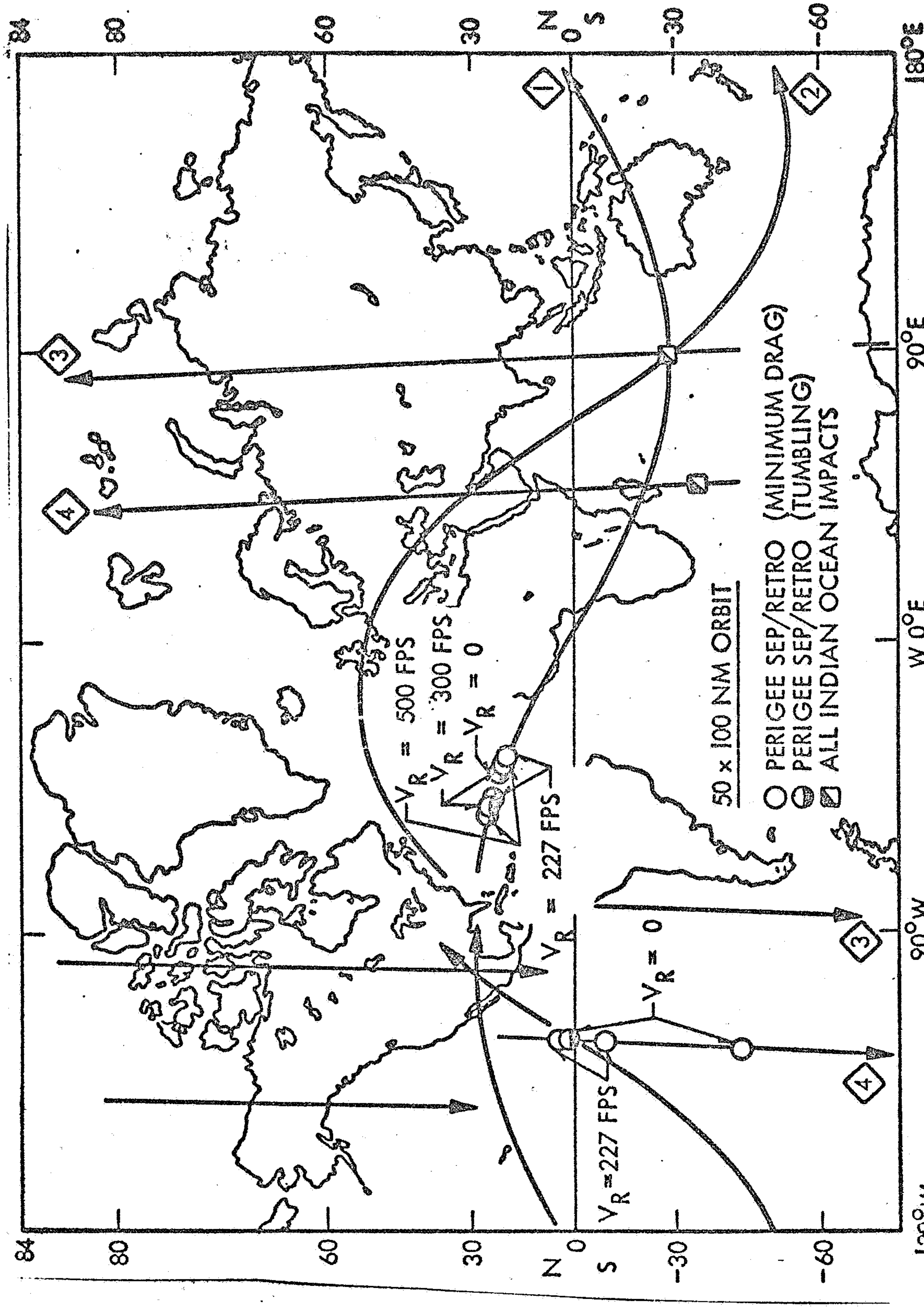

Fig. 5-2 Impact Location Summary

Fig. 5-2

The computer program used in the analysis is an LMSC 6D arbitrary body program capable of defining body motion, acceleration, and angle-of-attack histories during powered and/or unpowered flight of an unguided configuration. Initial conditions for 6D simulations are shown in Table 5-5. Mass properties, including time variations in weight, center-of-gravity (c.g.) and moments of inertia, are from EM L2-12-M1-1 (see Appendix).

Table 5-6 contains a list of parametric variations investigated in the study. Cases 2 and 3 included tumble rates induced at 10 sec after separation with a thrust moment applied about the Y_B axis for 0.5 sec.

The referenced engineering memo presents tank entry trajectory and total angle-of-attack histories for 6D dynamic simulations for the 28.5 deg orbit mission. A comparison of point mass (3D) trajectory histories for ballistic coefficients of 9.3 lb/ft^2 and 110 lb/ft^2 with the Case 1 (6D) entry is shown in Fig. 5-3.

Table 5-5

INITIAL CONDITIONS FOR 6D TRAJECTORIES

- Orbit 1 ~ I = 28.5° (ETR)
- Indian Ocean Impact
- Separation Time, 21.0 min
- Separation Velocity, 35 fps
- Separation Pitch Rate, 5 deg/sec
- Retro Velocity, 227 fps
- Retro Pitch Angle, 37 deg
- Separation/Retro Sequence

  Time = 0 to 2 sec, coast
  = 2 to 7 sec, retro-fire
  = 7 to 8 sec, coast
  = 8 sec, jettison retrorocket and hardware

Table 5-6

LIST OF INITIAL BODY CONDITION VARIATIONS FOR PARAMETRIC SIX-DEGREE-OF-FREEDOM TRAJECTORIES

Case No.	θ_R (deg)	η_o (deg)	p_o	q' (deg/sec)	Remarks
1	37	36.7	0	5	Nominal case
2	"	"	"	"	Induced Tumble — 5 RPM @ 10 sec
3	"	"	"	"	Induced Tumble — 10 RPM @ 10 sec
4	"	"	"	"	Forward C.G. Shift
5	"	"	"	"	Aft C.G. Shift
6	"	"	"	"	Plus Yaw Misalignment of Thrust Vector
7	"	"	"	"	Minus Yaw Misalignment of Thrust Vector
8	"	"	"	"	Plus Pitch Misalignment of Thrust Vector
9	"	"	"	"	Minus Pitch Misalignment of Thrust Vector
10	"	"	"	0	Same as nominal but all angular rates zero.

3-SIGMA CENTER-OF-GRAVITY LOCATION DEVIATIONS

Longitudinal ($\Delta \ell cg$)	Aft Deviation (ft)	Fwd Deviation (ft)
Separation	+0.833	-0.917
Retro Ignition	+1.667	-1.666
Retro Termination	+1.667	-1.666
Entry	-1.667	-1.583

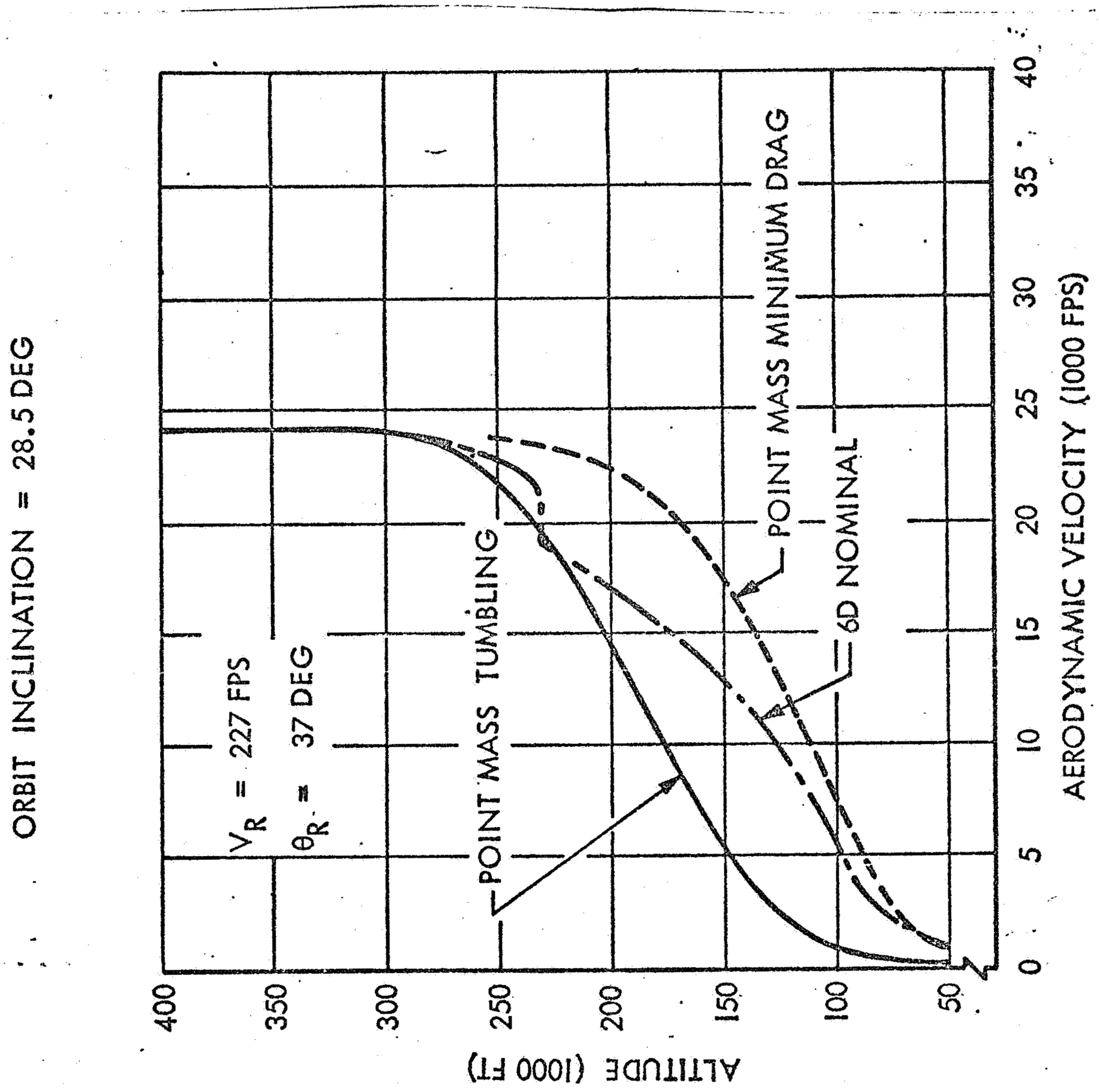

Fig. 5-3 Comparison of Point Mass and 6D Trajectory Profiles - Indian Ocean Impact From Orbit 1

Fig. 5-3

5.5 RANGE SENSITIVITIES AND IMPACT DISPERSIONS

Important to droptank deorbit operations and impact point selection is the sensitivity of entry range to parametric variations in orbital tank performance and tank mass characteristics. A detailed analysis of the sensitivities is reported in EM L2-12-05-M1-8 (see Appendix). Highlights of this analysis are reported herein.

5.5.1 Range Sensitivities

Range sensitivities were calculated for a variety of parameter changes assuming tumbling entry from a 28.5 deg inclined orbit and a 55 deg inclined orbit with impact in the Indian Ocean.* Parameters having the greatest effect on range are orbit elements (H, V_{Io}, γ_{Io}) and retro conditions (V_R, θ_R). Errors due to ballistic coefficient variations and azimuth deviations at retro are least contributors. Comparable sensitivities are presented for minimum drag entry conditions. There is a similarity in the magnitudes of various range deviations denoting little effect of changes in orbit inclination and small differences in retro initiation time. These similarities exist for all deorbit trajectories for Indian Ocean impact.

Retro at perigee decreases the magnitude of range errors because of the lower retro altitude and shorter flight times. Reducing V_R to zero at perigee, however, considerably increases range sensitivities to all parameters.

The effects of droptank dynamic flight characteristics are illustrated by comparing impact locations of the various 6D trajectory simulations with the corresponding point mass trajectory impact. All 6D cases fall within a 125-nm radius of the point mass condition except Case 4 (entry with a forward c.g. location.) Early convergence to trim for this case and the resulting high lift trajectory extends the relative range 600-nm downrange with a crossrange of about 160 nm. The nominal 6D trajectory impact is within 10 nm of the predicted point mass location.

* Data are based on point mass trajectory simulations.

5.5.2 RSS Impact Range Dispersion

Because of the apparent similarities of range sensitivity to parametric variations, 3σ impact range dispersions were calculated for a single representative entry trajectory. The case selected, entry from orbit 1 to an Indian Ocean impact, is typical of the various trajectories offering near maximum range. Consequently, dispersions for this case represent a near maximum expected impact envelope for an intact entry of the droptank.* Higher V_R and/or retro at perigee should result in smaller dispersions at impact.

Root-sum-square (RSS) dispersions were computed for assumed 3σ parametric errors. Impact range deviations for 6D trajectories were assumed for c.g. error and retro misalignments. All other sensitivities shown are from Fig. 18 of EM No. L2-12-05-M1-8 in the Appendix.

Total downrange dispersion for single tank is 1010 nm downrange, 763 nm uprange, and +32 nm, -174 nm in crossrange. The effect of a forward c.g. shift is the prime contributor to the asymmetry in both intrack and crossrange about the nominal.

5.5.3 Tank Breakup Considerations

The entry analysis to this point assumes the LH_2 droptanks will descend structurally intact to impact. In actual operations, however, the tanks may fail structurally, either by design or by chance, scattering fragments as they descend. An analysis of fragment ranges was performed to aid in prediction of any extension of the dispersion envelope which may be necessary because of breakup.

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*The correlation is not valid for the extended range non-retro ($V_R = 0$) entry from perigee.

Fragment ranges vary from 4400 nm to 6650 nm for the W/C_DA range considered. Assuming a particle spectrum of 5 psf $\leq (W/C_DA) \leq$ 500 psf, an impact range increase (over intact point mass tumbling entry) of about 1500 nm can be expected. This means most fragments will fall within the dispersion ellipse previously established by the 3D/6D analyses.

Fragment ranges for assumed tank breakup at the times of peak heating and peak dynamic pressure for entry from each of the four orbit conditions were also analyzed. The effects of breakup along a tumbling vs. a minimum drag trajectory were determined. Fragment ranges are reduced considerably for corresponding magnitudes of W/C_DA indicating that it is desirable to delay breakup as long as possible to reduce resulting fragment impact range envelopes. (See EM L2-12-05-M1-8 in Appendix for detailed analysis.)

5.6 RETROROCKET MOTOR COMPARISON

Section 5.2 of this report presents an analysis of the requirements for a droptank retrorocket motor. This analysis attempted to select a suitable motor from an assortment of hardware currently available. Two models were found acceptable - the LPC Javelin (2.4 KS 24,400) and the Thiokol TE-M-416 (8.3 KS 10,966). However, due to the low impulse-to-weight ratio of these currently available motors and the possibility of developing new motors with higher impulse-to-weight ratios and lower production costs, a tradeoff study was made to evaluate the program cost effects of new versus existing motors. Table 5-7 presents results of this tradeoff study.

By using existing CERs for solid rocket motor development and production, and a weight sensitivity value of $8,000/lb for the rocket motor weight penalty, it was determined that a total program savings could be achieved by developing a new lightweight droptank program-peculiar retrorocket motor.

Table 5-7

Retrorocket Motor Tradeoff Study

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	SOLID ROCKET MOTOR DESIGNS FOR 10,000 LB DROPTANK			
	THIOKOL TE-M-416 (8.3 KS 10,966)	NEW TE-M-416 TYPE	LPC JAVELIN (2.4 KS 24,400)	NEW JAVELIN-TY
* SOLID MOTOR WEIGHT	(+204 LB) $ 1.6	(756 LB) REF WT	(+232 LB) $ 1.9	(504 LB) REF WT
** DEVELOPMENT COST	$ 0	$ 3.8	$ 0	$ 3.3
** PRODUCTION COST	$195	$178	$188	$146
COMPARISON TOTAL	$196.6	$181.8	$189.9	$149.3
RELATIVE COST	$+14.8	REF	$+40.6	REF

* DROPTANK WEIGHT SENSITIVITY = $8,000/LB
** FROM MDAC REPORT G975: OPTIMIZED COST/PERFORMANCE DESIGN METHODOLOGY

Table 5-7

Section 6

SYSTEM REQUIREMENTS

It is premature to specify droptank requirements to any substantial depth and certainty because much information about the Orbiter/Booster and overall system operations are not well understood at this time. However, various analyses, trades, and optimizations present indications and guidelines pointing toward an anticipation of what the eventual requirements shall be. A summarization of definable requirements is presented in EM L2-12-M1-3.

6.1 ORBITER/DROPTANK INTERFACE

This section references those studies and data which would eventually evolve into definitive interface requirements.

6.1.1 Functional Interface

The principal functional interface elements are:

- Propellant system
- Pressurization system
- Electrical/power/instrumentation

There will also be maneuvers required of the orbiter before and after tank separation. These functional requirements are briefly summarized and referenced in Table 6-1.

Table 6-1

Orbiter/Droptank Functional Interface

Functional Operation	Requirement Reference
1. Propellant System	Described in Section 12 of this report.
2. Pressurization System	Described in Section 12 and EM L2-12-03-M1-1. This analysis is for a tank with ascent insulation and TPS. Further work is required to analyze the case requiring ascent and entry protection.
3. Electrical/Power/ Instrumentation	Described in Section 13 and EM L2-12-03-M1-1 and EM L2-12-03-M1-2.
4. Orbiter Maneuver	Probable orbiter maneuver requirements are discussed in Section 5.

6.1.2 Physical Interface

The physical interface elements are:

- Structure attachment locations
- Loads
- Control effects
- Thermal protection system
- Tank residuals

These elements are summarized and referenced in Table 6-2.

Table 6-2

Orbiter/Droptank Physical Interface

Physical Relationship	Requirement Reference
1. Structure Attachment Stations	Discussed in Sections 17 and 18 and also shown in Drawings SKG 100721 and SKS 100722.
2. Loads	The loads affecting the Orbiter are discussed in Section 10 and EM L2-12-01-M1-12.
3. Flight Control Effects	The droptank effect on flight control is discussed in Section 2.
4. Orbiter TPS	The orbiter TPS resulting from tank/orbiter interference heating is discussed in EM L2-12-01-M1-7.
5. Tank Residuals	The droptank GH_2 residual is discussed in Section 12 and EM L2-12-03-M1-1. No analysis of the LH_2 residual was conducted.

6.2 EXTERNAL LH_2 TANK REQUIREMENTS

It is not possible at this time to definitively characterize the LH_2 tank because of a lack of overall system requirements and definition. Table 6-3 references the analyses which serve to establish the basis for subsequent analysis and requirements definition.

Table 6-3

External LH_2 Tank Requirements

	Tank Element or Operation	Requirement Reference
1.	Structure Material and Structure	Aluminum 2219 T-81 and T-87. Sections 17 and 18 EM L2-12-01-M1-13 and Drawing SKT 100709 and SKG 100719.
2.	Max. Pressure and Wall Temperature	Section 10 and EM L2-12-01-M1-13.
3.	Electrical, Power, and Instrumentation	Section 13 and EM L2-12-03-M1-1 and EM L2-12-03-M1-2.
4.	Retrorocket	Section 5 and EM L2-12-01-M1-1 and EM L2-12-05-M1-8.
5.	Mechanical/Separation and Attachment	Section 4 and EM L2-12-02-M1-1 and EM L2-05-M1-8. Drawings SKG 100721 and SKS 100722.
6.	Loads	Section 10 and EM L2-12-01-M1-12.
7.	Insulation and TPS	For ground hold and ascent only: Section 11 and EM L2-12-01-M1-7 For ground hold, ascent, and entry: Section 11 and EM L2-12-01-M1-10.

6.3 ENTRY REQUIREMENTS

The problem of intact entry is peculiar to the Shuttle program and stems from the desire to assure maximum safety for personnel and equipment at impact. Impact dispersion is important insofar as it affects the possibility of land impact and ranges into areas of high shipping densities, although the latter is a relatively minor consideration. Intact entry not only reduces the overall dispersion, but minimizes the number of pieces of debris which can potentially cause damage. For a fixed entry system, the probability of impacting a "target" is not directly proportional to the number of pieces (because the size of the pieces affects the "hit" probability and the piece size will change as the tank unit breaks up), but the hit probability will increase as the number of pieces increases. Although there is a definite weight penalty for intact entry, as long as impact safety is a requirement, it is desirable to minimize the number of entering pieces because:

(1) Prediction of the characteristics of the entering body is greatly enhanced, and thereby the dispersion.
(2) When and how a tank will breakup is extremely difficult to predict, not to mention the characterization of in-flight debris.
(3) "Hit" probability is minimized.

The possibility of tank disintegration has been suggested, but a feasible method of accomplishing it has not been determined.

The following are some generalizations which may be made with regard to tank entry design requirements and operations:

- If the tank is of a balanced, neutral configuration, a tumbling entry is desirable because the related loads, range, and dispersions will be minimized.
- If it is apparent from the aerodynamics and mass data for a given tank configuration that it will definitely trim during entry, then it is prudent to focus the design activity on enhancing a trim at low angles since this will minimize the TPS weight.
- Higher retro velocities offer advantages of shorter range and reduced dispersions although system weight increases.

- Indian Ocean impact locations are practical for all the shuttle missions considered. Atlantic Ocean impact is only practical for WTR-launched orbits or 28.5 deg inclined orbits launched from ETR.
- Orbit elements, retro conditions and droptank c.g. characteristics are critical contributors to impact range dispersions.
- An elliptic dispersion envelope with axes of 2020 nm and 400 nm will contain all predicted range errors and most of the anticipated fragment impact locations.
- Intact entry approximately doubles the tank insulation and TPS weight for tumbling or shallow trimmed entry.

Section 7
SYSTEM EVALUATION METHODOLOGY

One of the most important tools required by designers is a method for comparing design alternatives which assures selection of minimum program cost/maximum effectiveness solutions. The method used in this study reduces as many of the evaluation factors as possible to total program cost so that the selection process can be made clearly on a cost-optimum basis. During the course of the external droptank program, many alternate design solutions have been conceived, laid-out, and studied in an attempt to first synthesize the total problem and then analyze those key areas leading to satisfactory design solutions. These key areas of concern are listed in Table 7-1, and are the subjects of the tradeoffs performed in this study and presented in those sections where they apply.

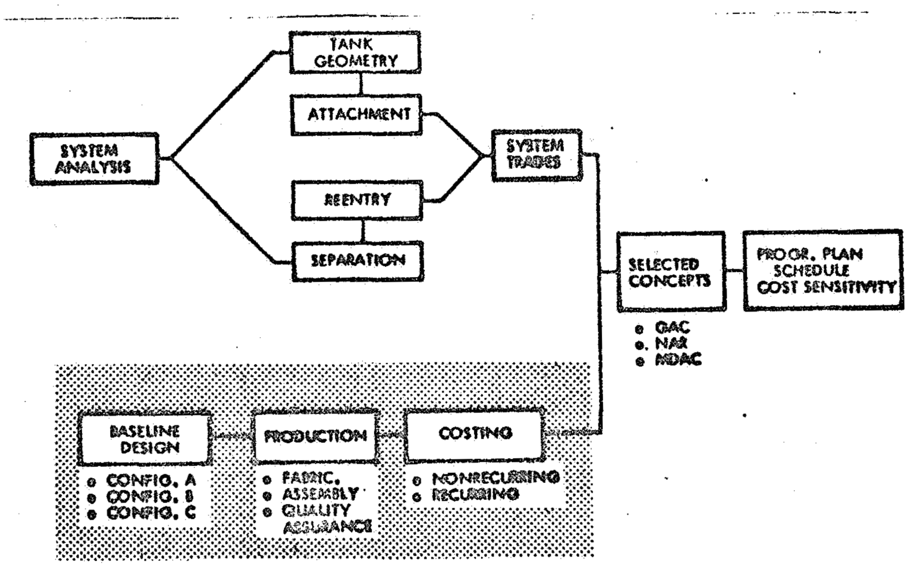
This cost-optimized evaluation method considers the factors of cost, performance, weight, reliability, safety, technical risk, and development time. In effect, all these factors are either converted to program costs or are equalized so that selections can be based purely on cost. First, each study item was designed to meet the performance required; then, for each candidate design solution, the relative evaluation factors listed above were estimated. Differences in technical risks and development times were converted directly to development cost dollars. Differences in weight were converted to total program costs, using a weight sensitivity factor determined for the droptanks and orbiter. The analysis uses a weight sensitivity factor of $8,000/lb* as the programmatic impact for carrying additional weight. (See Section 22.6 for weight sensitivity cost breakdown.) The effects of reliability and safety were incorporated into the basic design as performance constraints and were costed in whatever category they affected, i.e., design, production, DDT&E, etc.

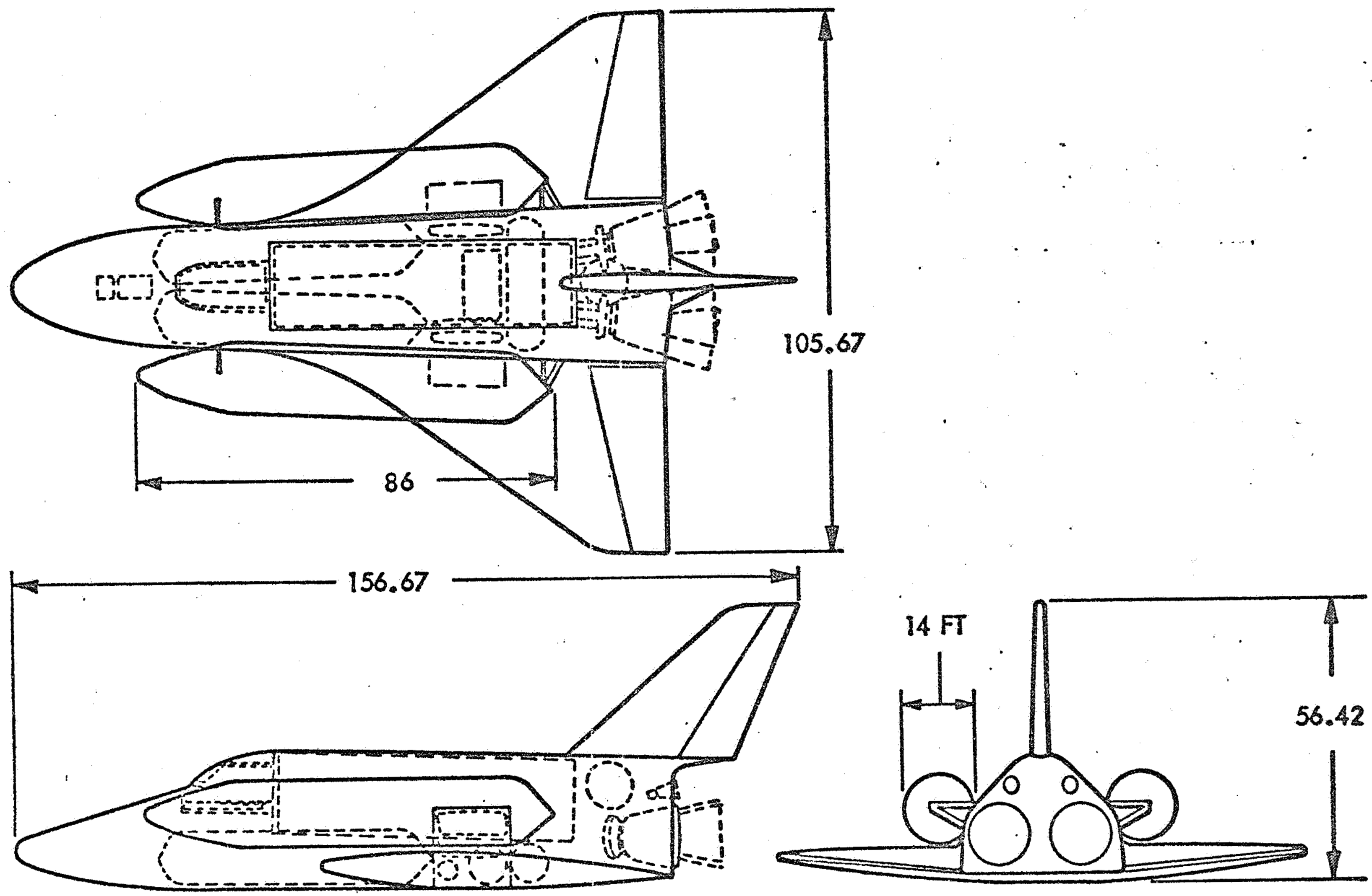
*This is the program cost penalty for carrying an additional pound on the orbiter/droptank stage and does not include the cost of the additional pound of hardware carried.

Part II
BASELINE DESIGN DEFINITION

Part II describes the activities associated with defining a baseline droptank system as highlighted in the figure below. For this activity, requirements were derived from the GAC external tank orbiter definition as it existed at the beginning of this study (see figure on next page).

The report describes the derivation of three baseline candidate designs (Configurations A, B, and C) utilizing results of a materials and producibility analysis. It also describes the utilization of these three baseline designs in performing a detailed analysis of manufacturing and quality assurance concepts associated with these designs, leading to a bottom-up estimate of the total program cost for Configurations A, B, and C. The results of all tradeoff studies performed in Parts I and II are summarized at the end of this part, as ready reference for future applications.





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Input for Baseline Design (GAC)*

*Source: GAC/Boeing, Alternate Space Shuttle Study, Tenth Monthly Report, 28 April 1971

Section 8
PRODUCIBILITY ANALYSIS

The producibility analysis was oriented toward defining materials, processes, and joining methods which yield a low-cost, lightweight droptank configuration. Only materials and processes which could be assumed available by the end of 1972 were considered. Primary considerations used for material selection were strength-to-weight ratio over the applicable range of operating temperatures, fracture toughness, weld allowables, and cost; and for process selection, considerations were availability of material stock and process equipment. Primary considerations for the process analysis were cost-effective utilization of existing equipment, gages, and tolerances of available material stock and influences of processes on material conditions. Producibility analysis led to the formulation of seven (7) candidate tank structural concepts from which three (3) baseline tank configurations (Configuration A, B, and C) were selected for detailed design analysis.

8.1 MATERIAL CONSIDERATIONS

Minimum cost, maximum reliability, and minimum weight were fundamental criteria for consideration in selection of a material from available candidates.

8.1.1 Basic Material Costs

The following tabulation indicates as a first approximation the relative range of cost for the as-received material prior to fabrication:

Material	Cost Range ($/Lb)
Aluminum Alloys Austenitic Stainless Steel Magnesium Alloys	1-3
Titanium Alloys	6-20

Material	Cost Range ($/Lb)
Glass Filament Winding	4-100
Carbon Composites Boron Composites Wrought Beryllium	100-300

8.1.2 Considerations for Material Selection

Selection of a material for liquid hydrogen droptanks must be predicated on manufacturing experience and on knowledge of the chemical and mechanical behavior of the processed product. Minimum cost of the material does not necessarily relate to the final cost of the end product due to varying costs required in the fabrication process to assure required tolerances and minimum weight.

For example, a material may demonstrate the highest strength-to-weight relationship for design of the lightest tank. However, this material may possess a low tolerance to imperfections. Consequently, the approach for manufacture would demand extremely sophisticated (costly) procedures to minimize flaws and of necessity the associated costs for nondestructive inspection would be high. Nondestructive inspection could never be absolute in assuring that the tank would be free from deleterious flaws and proof testing is the only positive method to detect assuredly such flaws. Nevertheless, on proof testing the tank must not fail catastrophically if the candidate material does possess a flaw. Sole reliance on the proof test to screen fabricated high strength-to-weight tankage that has low tolerance for flaws, when the probability of their presence is high, can be a very costly procedure.

Alternatives would include increasing the thickness of the high strength-to-weight material to effectively operate and to be proof tested at lower stress levels in order to provide a tolerance level for imperfections, or implement tankage design with a candidate material that not necessarily compromises weight, but assures both maximum reliability with attendant tolerances to imperfections and minimum cost.

This philosophy is the basis from which the evaluation of candidate materials has been conducted. On the basis of strength-to-weight ratios in conjunction with fracture toughness, three classifications of alloys offer the most promise for cryogenic tankage: (1) aluminum alloys that contain copper, (2) alpha phase titanium alloys, and (3) cold-worked stable and meta-stable stainless steels. These three alloy systems exhibit the highest strength-to-weight ratios. Recent experimental efforts have been devoted to determining the fracture toughness, threshold stress-intensity factors and cyclic flaw-growth behavior of the more promising alloys. These include aluminum alloys 2219, 2021, 2014, titanium alloy Ti-5Al-2.5Sn. Fracture toughness for each material was evaluated at -423°F (liquid hydrogen), -320°F (liquid nitrogen), and ambient air. Only crude estimates for cryogenic usage can be made in terms of plane strain threshold stress-intensity for the fracture toughness behavior of the cold-worked stainless alloy 301 XFH. These estimates are based on plane stress fracture toughness and notched-to-unnotched tensile strength.

8.1.3 Alloy Selection

Analysis of recent information indicates that for material thicknesses required for minimum weight droptank usage, aluminum alloy 2219 in either -T81 or -T87 tempers and the stainless alloy 301 in the XFH condition have distinct technical and cost advantages over all other candidate materials.

Figure 8-1 presents strength-to-weight relationships for candidate alloys and Table 8-1 presents recommended design criteria. Included in Table 8-1 for the 2219 alloy are data for various tempers. Titanium alloys are not considered as candidates because of a 4 to 5 fold increase in material cost over the two selected materials.

Aluminum alloy 2219 raw material, either -T81 or -T87 temper, readily lends itself to cylinder design and fabrication. Manufacturing processes would be comparable for welding or chem-milling if required. No post-weld heat treatments are necessary.

The end domes may require intermediate thermal treatments, and these treatments would obviously relate to the final configuration. The processess are well established and fully understood. However, manufacturing of complex configurations to the 2219-T87 condition will require special and possibly costly procedures. It is far more economically advantageous to fabricate to the final 2219-T81 condition for acceptable properties with equal reliability at low costs. The -T87 temper requires a minimum of 6 percent of strain, whereas the -T81 requires only 1 percent of strain.

The 2219 alloy is readily weldable by both fusion and resistance-welding methods. Reliability is further enhanced by the probable occurrence of fewer imperfections in conjunction with the "forgiveness" or tolerance of the material to imperfections.

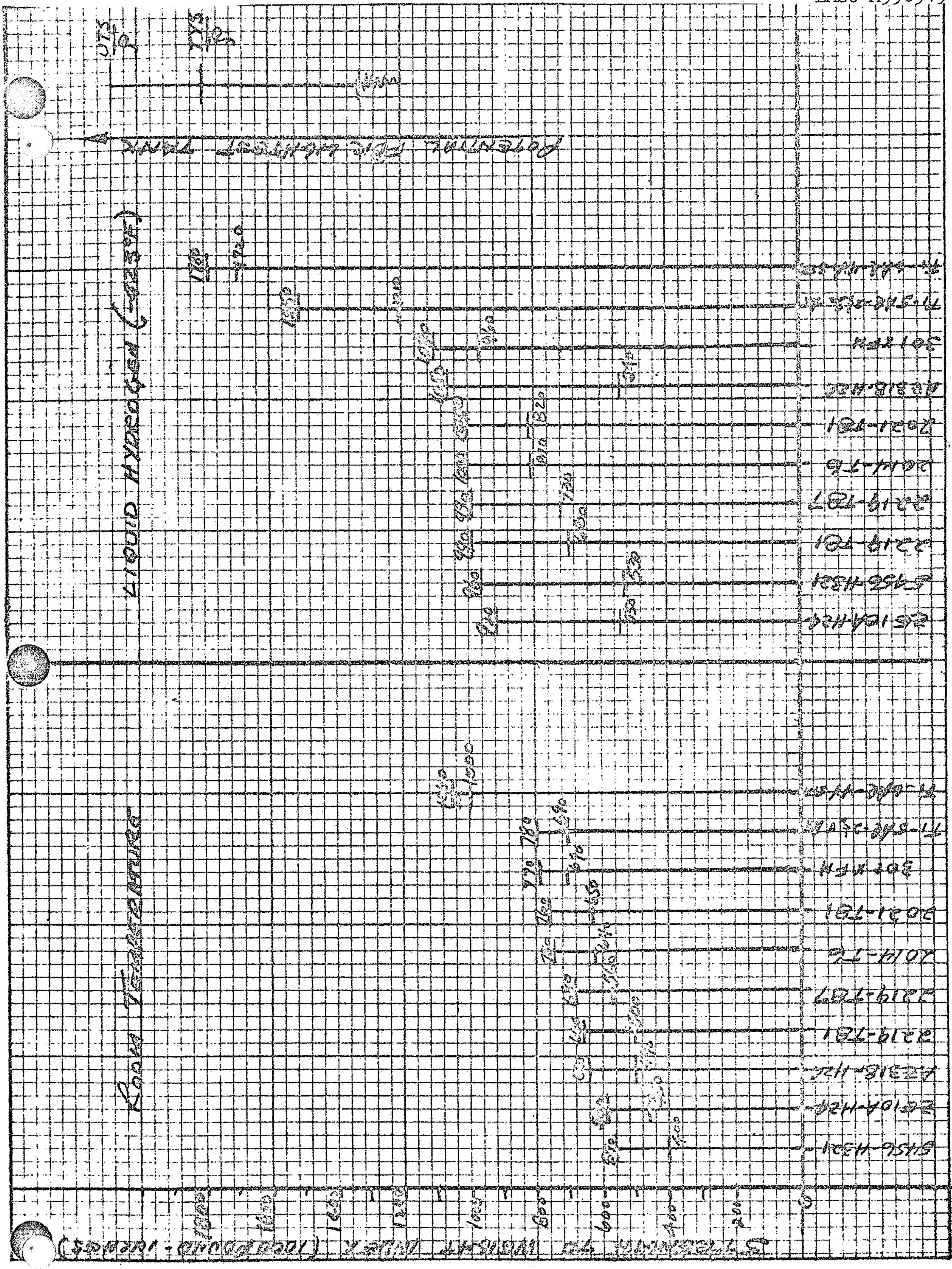

Fig. 8-1 Strength-to-Weight Comparison for Candidate Alloys for LH_2 Droptank

Table 8-1
RECOMMENDED DESIGN MECHANICAL PROPERTIES OF 2219 ALUMINUM AND STAINLESS 301 ALLOYS AT VARIOUS TEMPERATURES

Form	2219 Sheet & Plate*								301 XFH	
Condition	-T62	-T81	-T851		-T87			Weld	Base Metal	Weld**
Thickness	0.020 2.000	0.020 0.249	0.250 1.000	1.001- 2.000	0.020 0.039	0.040 0.249	0.250 1.000	.060 1.00	.010 -.030	.010*** .030
Temperature	(-423°)									
F_{TU}, ksi	85	94	94	94	95	95	95	35**	290	170
F_{TY}, ksi	49	61	61	61	68	69	68	-	260	
-percent	9	9	11	10	8	9	10		1	
Temperature	(-320°F)									
F_{TU}, ksi	67	77	77	77	78	78	78		290	190
F_{TY}, ksi	43	55	55	55	61	62	61	-	200	-
-percent	8	7	10	9	6	7	8		2	
Temperature	(-112°F)									
F_{TU}, ksi	57	66	66	66	67	67	67		200	-
F_{TY}, ksi	38	49	49	49	54	55	54	-	160	
-percent	6	6	9	8	5	6	7		2	
Temperature	(- 18°F)									
F_{TU}, ksi	55	64	64	64	66	66	66		200	-
F_{TY}, ksi	37	47	47	47	53	54	53	-	160	
- percent	6	6	8	7	5	6	7		2	
Temperature	(75°F)									
F_{TU}, ksi	54	62	62	62	63	63	63	35	200	120
F_{TY}, ksi	36	46	46	46	51	52	51	-	160	
-percent	6	6	8	7	5	6	7		2	
Temperature	(212°F)									
F_{TU}, ksi	49	56	56	56	56	56	56			
F_{TY}, ksi	33	41	41	41	46	46	46	-		
-percent	7	8	10	9	7	8	9			

* Values based on proposed revision to MIL-HDBK-5.
** Values given are tentative expected - minimum design properties, may be modified on actual weld schedules, including repair.
*** These welds are roll planished.

The alloy readily lends itself to forming, or machining either by mechanical or chemical means. LMSC has developed a special starting temper for the aluminum alloy when complex forming processes are employed. This condition permits in-process thermal treatment for stress-relieving when subsequent operations are required. The significance of this starting temper, designated -H210, permits complex forming operations without suffering intermediate forming problems associated with grain coarsening or attendant degradation to ductility after final heat treatment prior to finishing to either the -T81 or -T87 tempers, as required.

Utilization of 301 XFH would follow the same pattern outlined for the 2219 aluminum alloy. However, strengthening cannot be achieved by heat treatments. In-process thermal treatment may be necessary to enhance fabricability of complex sections. Further, limitations will be imposed upon complex tank-end configurations. The 301 XFH will lend itself readily to cylinder-type fabrication; compound or complex configurations may be formed to generous radii and then joined.

Fusion-welding of 301 XFH causes creation of a heat-affected zone and lower mechanical properties and sensitization. Weldments will require roll-planishing. Sensitization is a condition that may be conducive to intergranular corrosion if exposed to an aggressive marine atmosphere. Nevertheless, many years of space vehicle experience in such environments indicate the problem, if any, is minimal. The 301 XFH, although it is basically an austenitic alloy, converts to some degree of martensite on cold-working. This condition causes the material to be ferromagnetic. Final selection of a material for the shuttle system must recognize this phenomenon to avoid electromagnetic flight systems interference, if any.

8.2 PROCESS CONSIDERATIONS

Candidate manufacturing processes applicable to the production of the external droptank were appraised with special emphasis on developing a straightforward final assembly, having as few components as practical. These processes were related to the two materials selected: namely, 2219-T81/87 aluminum, and austenitic stainless steel AISI 301 extra full hard. The maximum sizes in terms of equipment capability and material stock were therefore prime factors which governed the final selection. Of the various processes evaluated, the forming operation was found to be most sensitive to material stock gages and sizes. For example, although 16-ft diameter spin lathes are available, thin gage sheet stock sufficient in size to produce a 14-ft diameter dome in one piece cannot be obtained either in aluminum or stainless steel. A different fabrication approach had to be considered.

Another critical factor influencing process selection is the process-property interaction. The aluminum alloy 2219 requires solution heat-treat, cold-work, and artificial aging, in that order, to develop either T81 or T87 properties; while 301 stainless steel requires about 60 percent cold work to reach extra full hard condition. The workability of each material at its various stages of condition, within each process, must be carefully considered to insure that the desired final properties are attainable. Because of this factor, although spin-forming at moderately elevated temperature is an economical process for many materials, with 2219 aluminum alloy the best attainable condition is T62 without subsequent heat-treatment and additional cold work. Therefore, it is not an acceptable process because it will not yield the required T81 or T87 condition.

Salient features of various fabrication processes investigated are discussed herein, with specific comments relevant to the designs being considered.

8.2.1 Forming

Both the cylindrical body and the end domes involve relatively simple geometry. The majority of their components involve only constant single curvature. The spherical segment of the aft dome is the exception which includes a uniform compound curvature. Of the many known forming techniques, only the following are applicable to the proposed designs:

Method	Equipment
Spin Forming	Spinning Lathe
Shear Forming	Shearform Machine
Stretch Forming	Stretch Press
Explosive Forming	Water Pool and Explosive
Roll Extrusion (for cylinders only)	Special Machine

Spin Forming is a fabrication technique utilized by sheetmetal fabricators for years. It is quite economical for producing bulkheads, domes, etc., having compound curvatures. This method usually induces considerable reduction in the material thickness, hence work hardening, which somewhat restricts its application to smaller size and/or softer material. Therefore, this process was considered primarily for the small polar segments of the end domes.

Shear Forming is a newer technique, as compared to spin forming. It is sometimes referred to as Sine Law spinning, since the final wall thickness of a spun cone can be determined by the sine angle function, as shown in Fig. 8-2. Plate thickness parallel to the centerline of the mandrel does not change during spinning; only the "normal" wall thickness is reduced. Note also that the plate diameter does not change during spinning. The specific reduction in normal wall thickness and the absence of diameter change is what differentiates shear forming from conventional spin forming. Some of the critical factors for successful shear forming are: (1) machine rigidity; (2) material characteristic; (3) thickness of the starting stock; and (4) the geometry involved. This process was considered for the aft dome.

SINE LAW FOR SHEAR FORMING

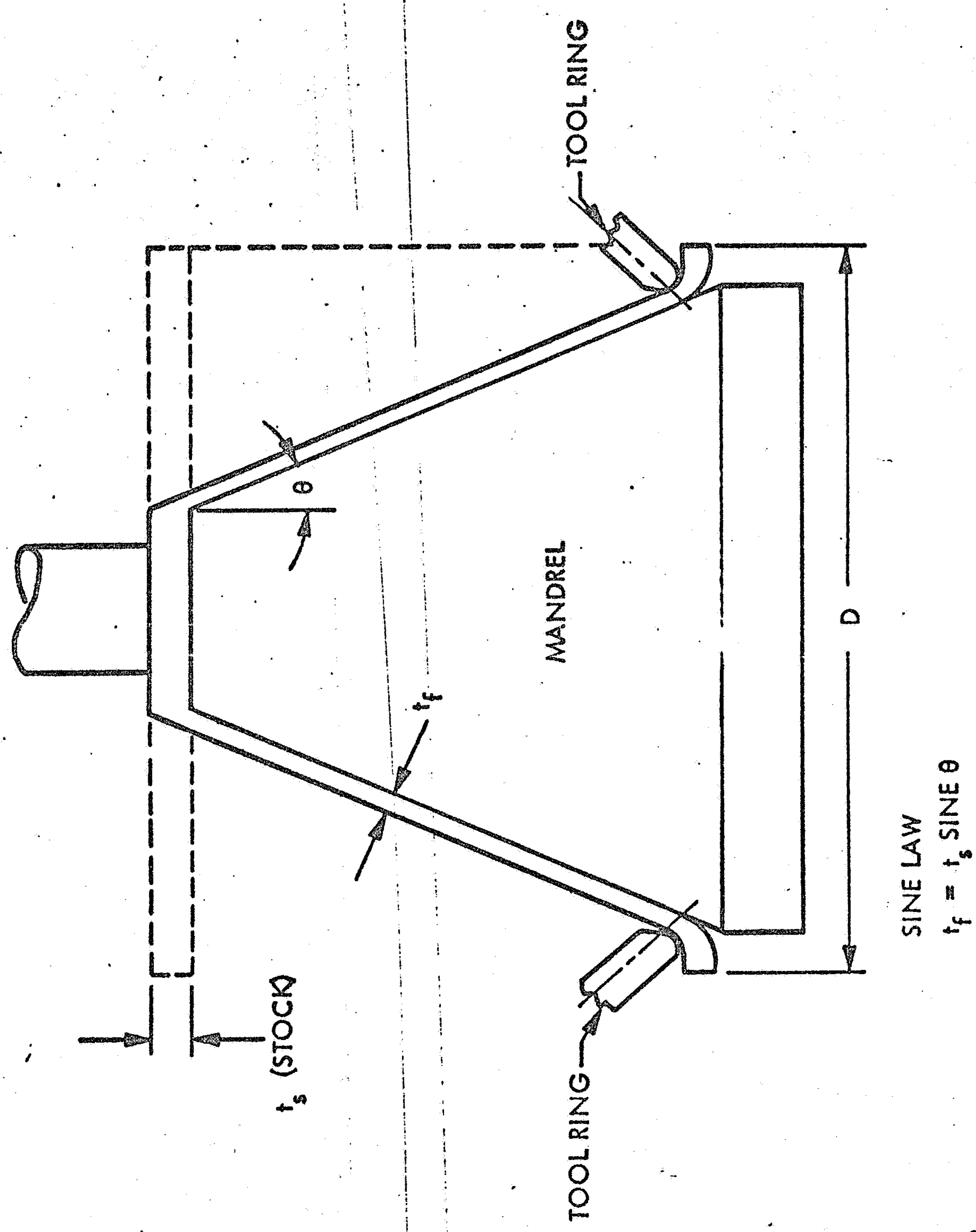

Fig. 8-2

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Fig. 8-2

With this technique, a one-piece, 14-ft diameter, 2219 aft dome is feasible by starting with plate stock at F temper. The largest shear-forming equipment in the U.S. has a 16-ft diameter capability and is scheduled to be installed at C. W. Torngrew Co., Inc., Sommerville, Mass., this year.

Although a thin-wall, 14-ft diameter monocoque barrel can be produced by shear forming, no machine in this country can produce a barrel longer than 7 ft, at that diameter. This results in too many sections for the cylindrical body, and hence excessive weld length.

If a suitable machine is developed, this may yet be the most cost-effective approach.

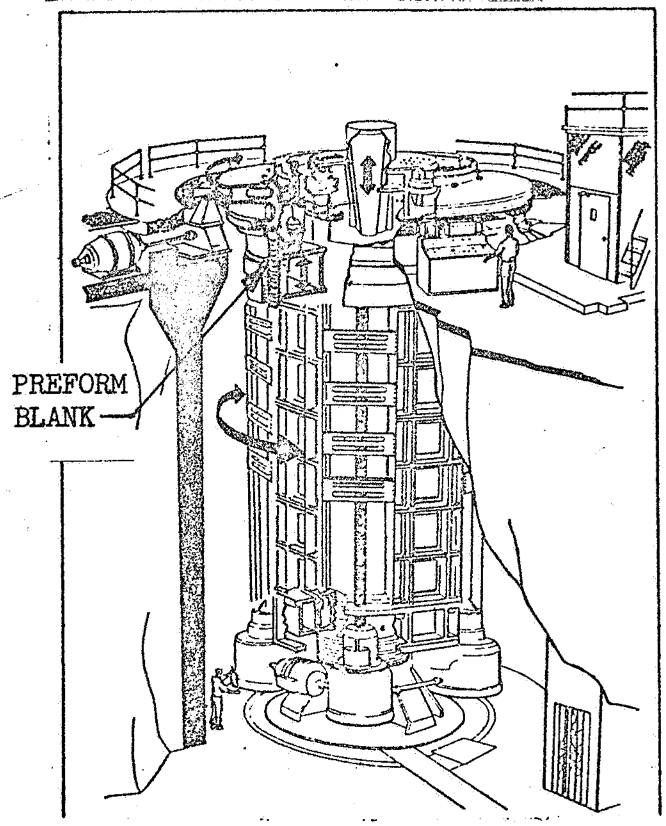
Stretch Forming is a process with which a sheet blank is stretch-formed over a male die. During the forming operation, various combined movements of both the jaws holding the edges of the blank and the male die can be obtained. The work is shaped into the desired compound curvatures, mostly under tension. This is a well-known process and will be considered for forming of large gore segments for the aft dome. It is a more economical process for this shape than that using a draw-forming technique with mating dies and draw ring.

Explosive Forming is one of several techniques for forming metals at high velocities and in a short time. The distinguishing characteristic of the various high-velocity forming methods is the power source and the rate of energy transfer to the workpiece; the energy source for explosive-forming is either high or low explosive. Forming action can be accomplished either with an open-die or closed-die system. Relatively good efficiency is obtained with open-die systems using high explosive with a water bath. This process is especially suited for large size and heavy gages. However, it is still somewhat an art and requires considerable experience and skill to develop economical results. During the early stages of Saturn V development, several large aerospace companies, including Lockheed, devoted considerable efforts to the application of this technique. Most of these facilities are now inactive, due to the reduction in space programs. Some of the personnel associated with the technology are now connected with commercial companies, such as Chemical Energy Co., San Diego, which has taken over Ryan's former activities.

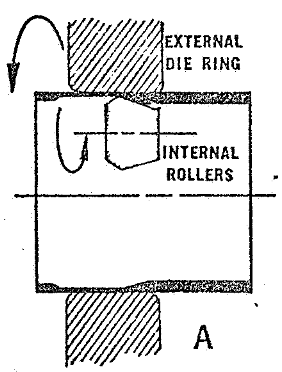
Because of its very short operating cycle using only low-cost explosives and water, explosive forming has very low recurring cost. Dies suitable for large quantity production are quite costly. The first steps in taking a flat blank to a formed shape usually cannot be accurately predicted and, generally, involve die modifications. This further increases tooling cost. Such risk is greatly reduced when this technique is used primarily for final sizing and work hardening such as with 301 stainless steel. Therefore, explosive sizing is being considered for sizing the aft dome from a fabricated cone.

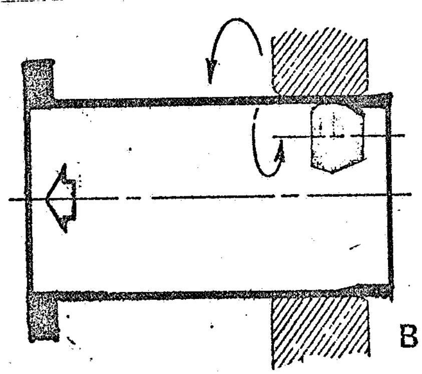
Roll Extrusion is a recent process technique developed for the Air Force in about 1965, by N.T.W. Missile Engineering, Inc. This process can produce one-piece, thin-wall monocoque barrels limited only by the capability of the equipment. A machine which can produce a 14-ft diameter by 13-ft long barrel is in use at the Ladish Company, Wisconsin.

This process is designed to take short, ring-rolled blanks and elongate, size, and shape them by either hot or cold working. The process deforms the workpiece by displacing material by the action of internal rollers within a die ring and the application of tension to the part being extruded. Precise dimensional control is inherent in this process, which sizes the part accurately as it is being roll-extruded in one or more passes into its final tubular form. A sketch of the equipment and working principle is shown in Fig. 8-3.



A Typical Roll-Extrusion Machine Shown With A Preform Blank At The Starting Position





A and B depict the roll-extrusion process which starts with a forged cup or ring blank contained in an outer ring. Internal pressure rollers work the metal from inside as the blank is moved through the ring.

Fig. 8-3 Roll-Extrusion Forming Process

With 13-ft or longer barrels, the desired cylindrical section of the droptank can be developed with either four or five barrels, resulting in a minimum of circumferential weld length. However, due to the pecularity of the process in conjunction with the only equipment available, this approach did not appear as cost-effective as other approaches.

8.2.2 Joining

Joining tankage components by fusion-welding, resistance (spot or seam) welding, or weld-bonding were compared in this study. The first two processes have been in practice for years and require no discussion.

The weld-bonding (LMSC terminology) process combines resistance (spot) welding with adhesive-bonding and has been recently developed by Lockheed for aluminum alloys. The procedures to be followed in the weld-bond process are very similar to those required in conventional resistance welding. The adhesive is applied to the precleaned joint and the spotweld is made through the adhesive, thus holding the joint securely for subsequent operation steps.

The adhesive is then cured at an elevated temperature. With the presence of a doubler strip at each butt joint, this process offers liberal fabrication tolerances for large structures, uses low-cost tooling and exhibits excellent fatigue resistance. The specific adhesive system, 3M-EC2214, adopted by LMSC, has survived LH_2 environment in many tests (Fig. 8-4). Results obtained to date with aluminum alloys have shown that a weld-bonded joint develops higher joint strength than either spot-welding or adhesive-bonding (Fig. 8-5).

For certain geometries, this is a very cost-effective joining process.

8.2.3 Chem-Milling

This is an economical process for reducing the thickness of a large tank component either locally or over the entire surfaces. For fusion-welded aluminum design, this is the method to develop membrane thickness and the

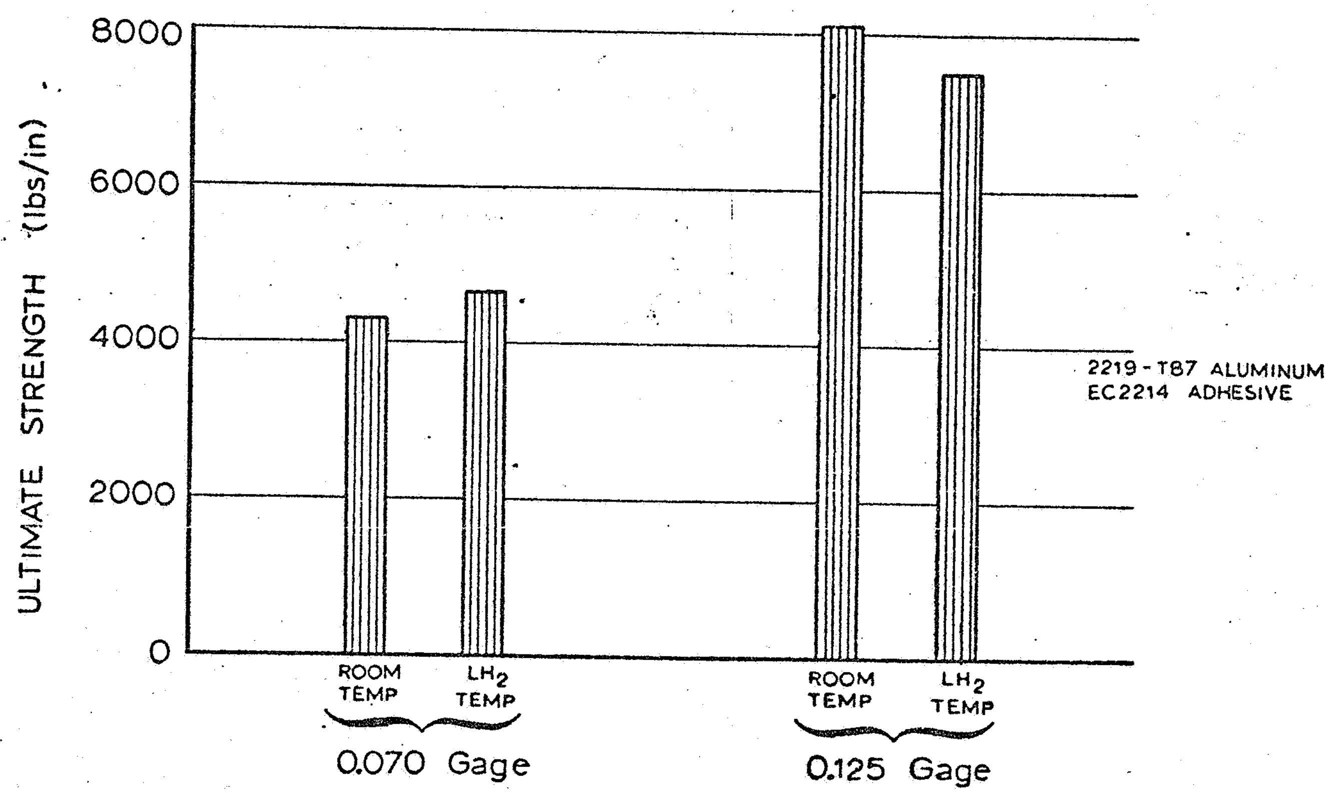


Fig. 8-4 Lap Shear Strength of Weld Bond Coupons at Cryogenic Temperatures

Ref: F. Sullivan, K. Forsberg, "Application of Weld Bond to Aerospace Structures," Jan. 1971, Lockheed Report LMSC-6-C5-70-1.

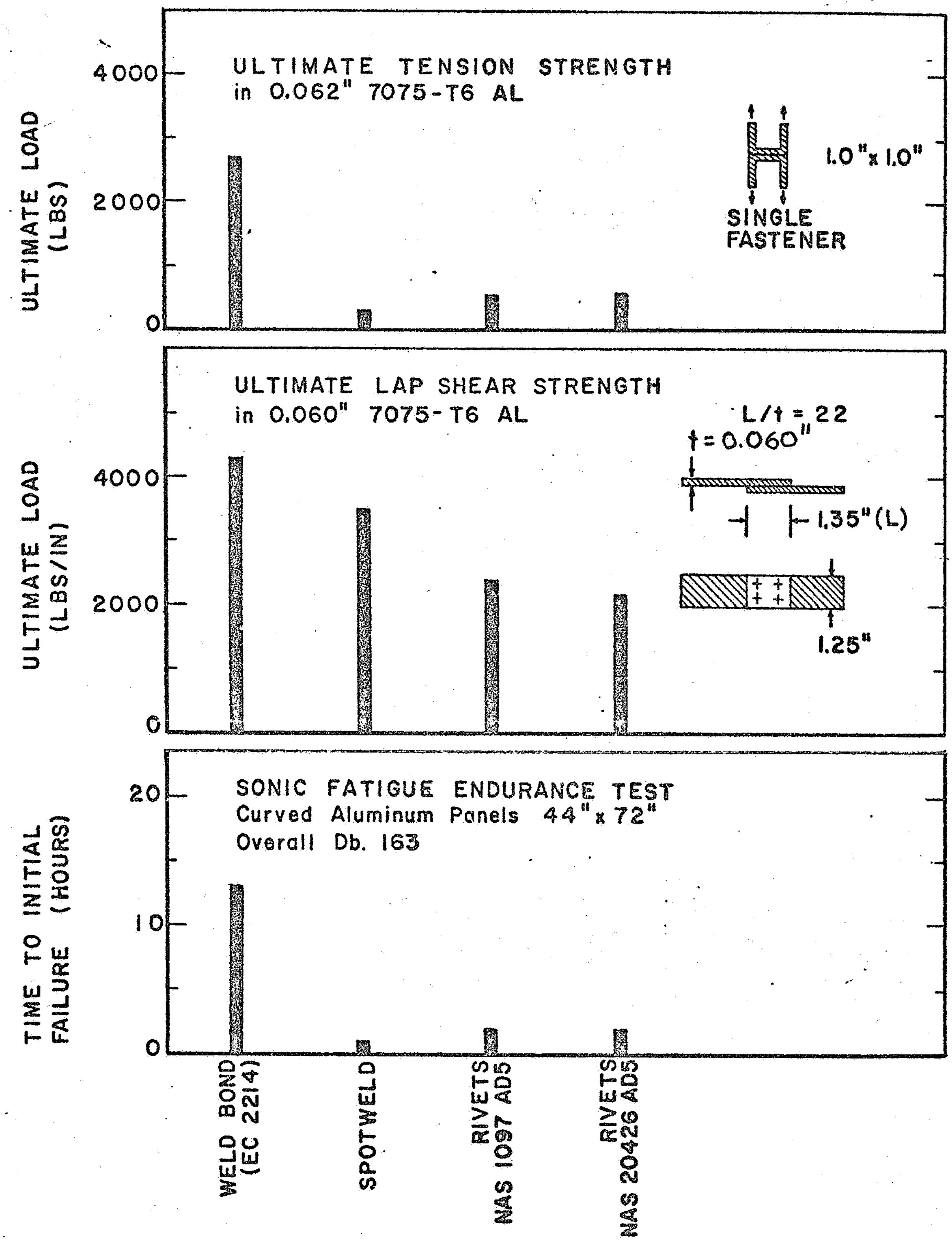


Fig. 8-5 Comparison of Joint Strengths for Weld Bond, Spotwelds, and Rivets

Ref: F. Sullivan and K. Forsberg, "Application of Weld Bond to Aerospace Structures," Jan 1971, Lockheed Report 6-C5-70-1 weld land patterns. Although very large chem-milling tanks, 25-ft dia by 20-ft deep, 10-ft by 60-ft deep, etc., are available in the industry, close thickness tolerance control is extremely difficult and costly for large-size components. Since extra-wide sheet, which bears broader thickness tolerances, must be used for fabricating large-size components, a requirement to hold very tight tolerances on final thickness must be accomplished with local mapping chem-milling technique, resulting in excessive hardware cost.

The cost involving local mapping is difficult to predict and is a function of the number of high spots, as well as the frequency of retrieval from the tank for measurement; therefore, it is not included in Fig. 8-6.

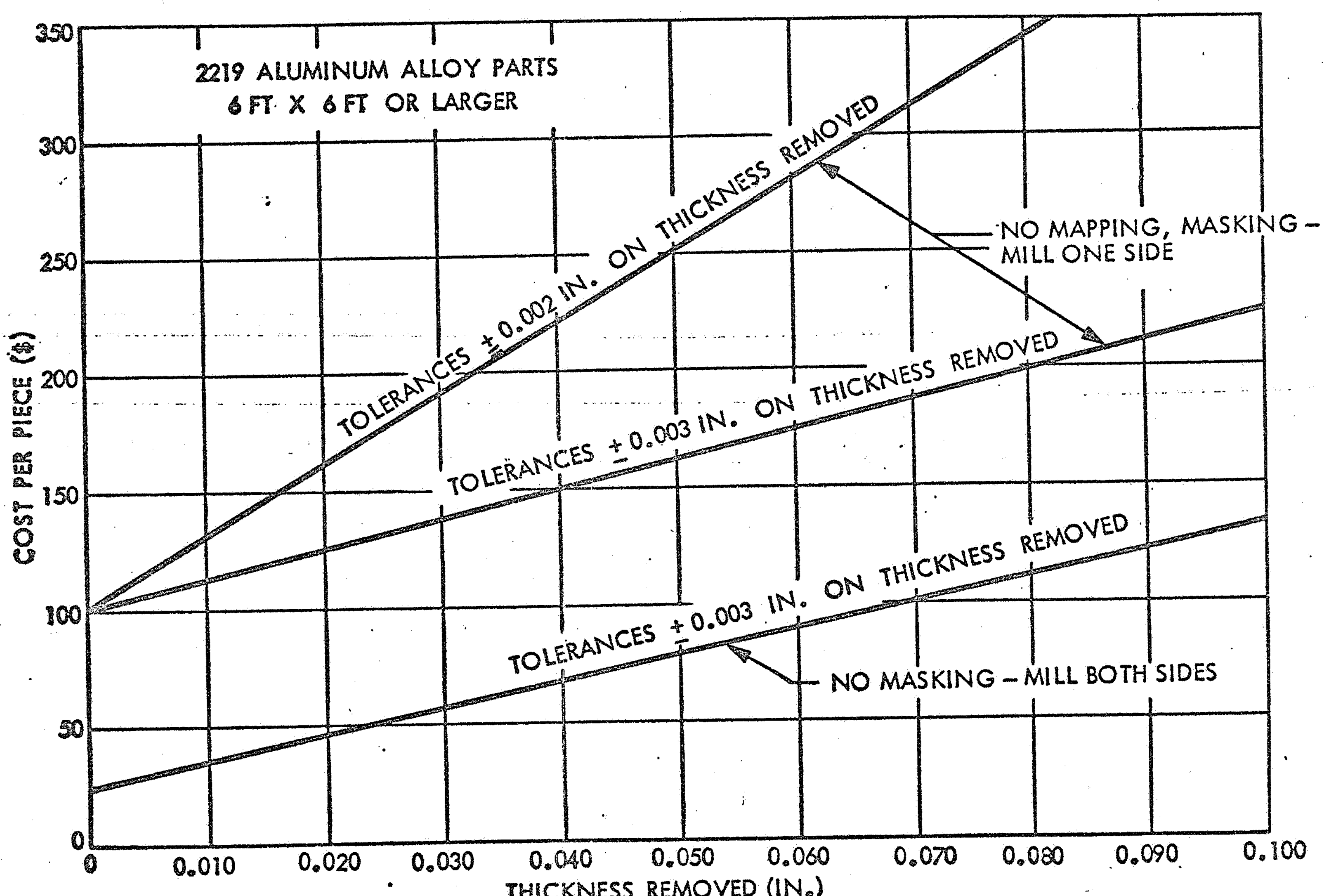
8.3 GEOMETRY CONSIDERATIONS

8.3.1 Material Availability

It should be emphasized that the intimate interaction between geometry, material, and process must be carefully considered, if a cost-effective design is to be developed. For example, thin-gage, large-size components such as gore panels, partial barrel segments, etc., distort readily when they are subjected to a heat-treatment cycle. Therefore, post-forming heat-treatment to develop 2219-T81/T87 properties must be avoided. Similarly, a hot spin-form process cannot be used when T81 or T87 properties are desired.

Another important factor which must be considered in design is the condition and size of material stocks available. Aluminum alloy 2219 sheets in a T condition must be heat-treated and cold-worked during the rolling operation at the mill. This imposes stringent limitations on both sheet width and thickness tolerance which, in turn, influence the size and costs of the component to be fabricated. Such relationships are shown in Fig. 8-7 and Table 8-2. As the stock thickness approaches the minimum value for a particular material, only narrow sheet or coil stock will be available. As in the case of 301 XFH stainless steel in the gage range being considered, the

CHEM-MILLING COSTS



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8-6

Fig. 8-6

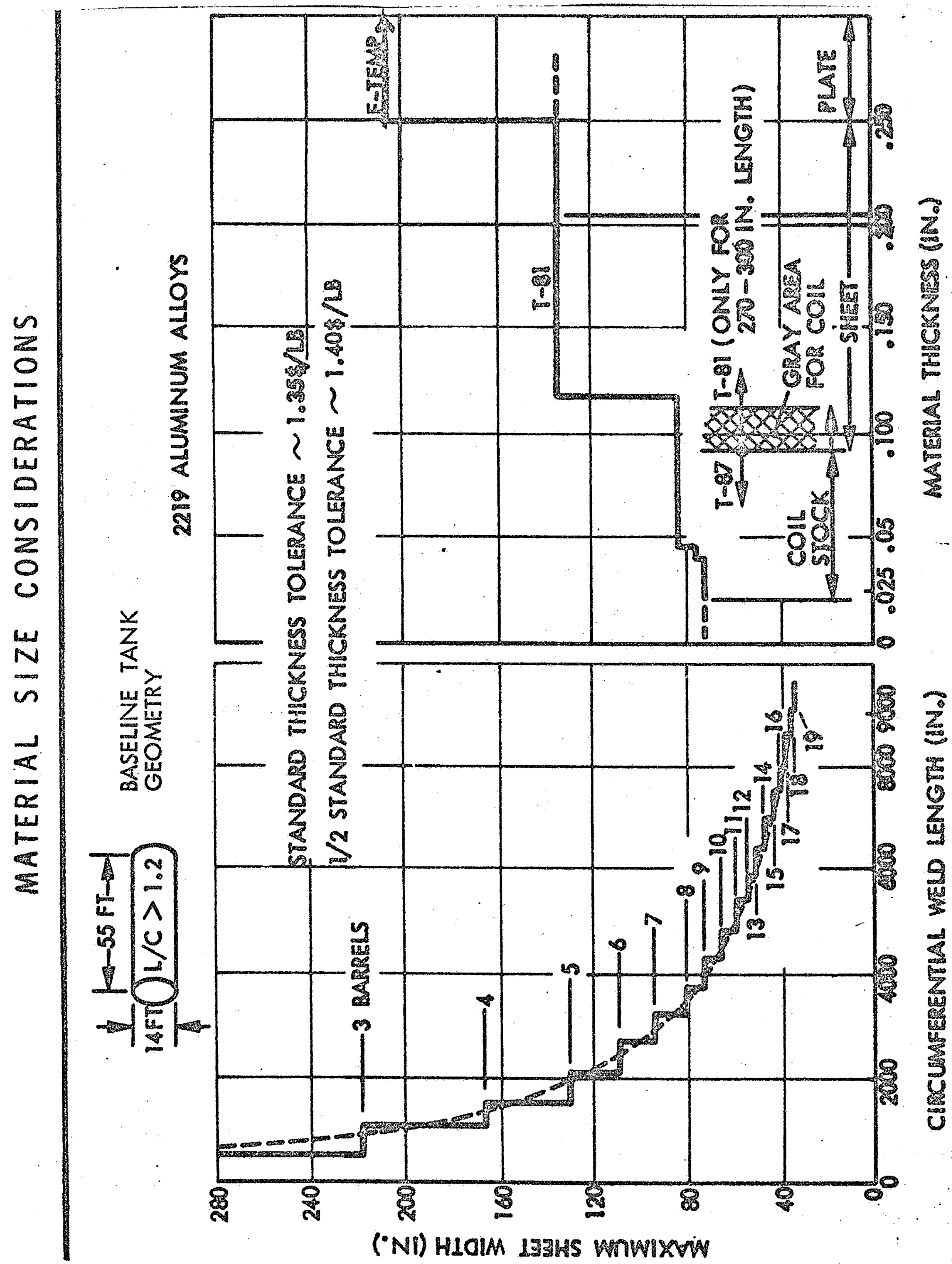

MATERIAL SIZE CONSIDERATIONS
BASELINE TANK GEOMETRY
55 FT
14FT
L/C > 1.2
2219 ALUMINUM ALLOYS
STANDARD THICKNESS TOLERANCE ~ 1.35$/LB
1/2 STANDARD THICKNESS TOLERANCE ~ 1.40$/LB
3 BARRELS
F-TEMP
T-81
T-81 (ONLY FOR 270 - 300 IN. LENGTH)
T-87
T-81
GRAY AREA FOR COIL
SHEET
PLATE
COIL STOCK
MAXIMUM SHEET WIDTH (IN.)
CIRCUMFERENTIAL WELD LENGTH (IN.)
MATERIAL THICKNESS (IN.)

Fig. 8-7

FIG. 8-7

Table 8-2

THICKNESS TOLERANCES

standard tolerances/sheet and plate*

ALLOYS 2014, 2024, 2219, 3004, 5052, 5083, 5086, 5154, 5252, 5254, 5454, 5456, 5652, 6061, 7039, 7075, 7079, 7178, AND BRAZING SHEET NOS. 11, 12, 21, 22, 23 AND 24.

NOTE: ALSO APPLICABLE TO THE ALLOYS LISTED WHEN SUPPLIED AS ALCLAD.

SPECIFIED THICKNESS Inches	SPECIFIED WIDTH—Inches														
	Up thru 18	Over 18 thru 36	Over 36 thru 48	Over 48 thru 54	Over 54 thru 60	Over 60 thru 66	Over 66 thru 72	Over 72 thru 78	Over 78 thru 84	Over 84 thru 90	Over 90 thru 96	Over 96 thru 125	Over 132 thru 144	Over 144 thru 156	Over 156 thru ~~160~~ 210
	TOLERANCE—Inches Plus and Minus														
0.006-0.010	.001	.0015	.0025	.0025	....	....	....	....	....	....	....	....	....	....	....
0.011-0.017	.0015	.0015	.0025	.0035	....	....	....	....	....	....	....	....	....	....	....
0.018-0.028	.0015	.002	.0025	.0035	.004	.004	.004	....	....	....	....	....	....	....	....
0.029-0.036	.002	.002	.0025	.004	.005	.005	.005	.006	.006	.007	.009	....	....	....	....
0.037-0.045	.002	.0025	.003	.004	.005	.005	.005	.006	.006	.007	.011	....	....	....	....
0.046-0.068	.0025	.003	.004	.005	.006	.006	.006	.007	.007	.008	.012	.013	....	....	....
0.069-0.076	.003	.003	.004	.005	.006	.006	.006	.007	.007	.012	.012	.016	....	....	....
0.077-0.096	.0035	.0035	.004	.005	.006	.006	.006	.007	.007	.012	.012	.016	....	....	....
0.097-0.108	.004	.004	.005	.005	.007	.007	.007	.008	.008	.016	.018	.020	....	....	....
0.109-0.125	.0045	.0045	.005	.005	.007	.007	.007	.008	.008	.016	.018	.020	....	....	....
0.126-0.140	.0045	.0045	.005	.005	.007	.010	.012	.013	.014	.016	.018	.020	....	....	....
0.141-0.172	.006	.006	.008	.008	.009	.012	.014	.015	.016	.017	.019	.023	....	....	....
0.173-0.203	.007	.007	.010	.010	.011	.014	.016	.017	.017	.017	.022	.026	....	....	....
0.204-0.249	.009	.009	.011	.011	.013	.016	.018	.018	.018	.018	.024	.028	....	....	....
0.250-0.320	.013	.013	.013	.013	.015	.018	.020	.020	.020	.020	.025	.030	.035	.042	.053
0.321-0.438	.019	.019	.019	.019	.020	.020	.023	.023	.025	.025	.026	.033	.038	.045	.057

*Closer thickness tolerance sheets at half of the standard tolerances shown can be obtained at a cost increase of about 5 percent above that of the standard tolerance sheets. These are called HALF TOLERANCE SHEETS.

Framed figures cover gage and size ranges plotted in Fig. 8-7.

maximum size stock available is 48-in. in 10,000 - 12,000 lb coils. Therefore, producibility analyses had to be based on the projected mill capability shown in Fig. 8-7. Since, for the tank size being studied, every 1 mil (.001-in.) increase in skin thickness equals about 50 lb increase in weight, thickness tolerance is a very important factor and should be kept to a practical minimum. In view of the high chem-milling cost for tight-thickness tolerance (Fig. 8-6) versus the small increase of 5¢/lb for 1/2 standard tolerance sheet stock (Fig. 8-7), the latter is used in all cases.

It is worthy to note that, although companies such as Alcoa, Reynolds, Armco Steel, U.S. Steel, etc., possess large mill capacities, none of them had a firm position on what was the widest sheet of 2219-T81/T87 that they could produce. Data presented in Fig. 8-7 are the results of numerous communications between LMSC and key personnel at the management levels at the several mills and are the best current estimates. This study is based on these estimates. It is believed that these limits can be somewhat exceeded when bonafide material orders are being placed for production requirements.

Producibility studies were conducted under two major groups, one covering the cylindrical body, the other the end domes. Under each group, the two selected joining methods, namely, fusion (or resistance) welding and weld-bonding were applied to the two selected materials. The studies conducted are summarized below.

8.3.2 Cylindrical Body

Three approaches to fusion-welded aluminum body are presented in Table 8-3, with only one approach to fusion (resistance) welded 301 XFH stainless steel. Because of the successful performance of the Atlas/Centaur system, and its close geometric similarity to the droptank being studied, the only fabrication approach considered for the stainless steel is based on the techniques qualified for the Atlas/Centaur system. Efforts directed to search for newer fabrication schemes, while there has been no advance in the condition and size of material stock, cannot be considered cost-effective. The producibility of four (4) fusion-welded approaches for the cylindrical body is summarized in Table 8-3. Similarly, Table 8-4 summarizes the two approaches using the weld-bond process.

8.3.3 End Domes

Guidelines adopted for the cylindrical body also govern the end domes. That is, only fusion-welding is being considered for the stainless material.

Aft Dome. The aft dome represents a more complex geometry for fabrication than that of the forward dome. Any fabrication process suitable for it will be equally applicable to the forward dome. In this case, Table 8-5 summarizes both fusion-weld and weld-bond concepts.

Forward Dome. Similarly Table 8-6 summarizes all concepts considered for the forward dome. The method for attaching the forward skirt is virtually identical for each approach and its fabrication and assembly have no significant effect on the comparison of the designs. Its producibility is therefore not included in the summary table.

8.4 CONCLUSIONS AND RECOMMENDATIONS

Manufacturing characteristics for 16 different design approaches, 6 for the cylindrical body and 10 for the end domes, indicated that several designs for each major segment can be quite competitive in terms of recurring costs. Tradeoff studies were carried further by combining the more favorable approaches into 7 different tank candidate configurations (Fig. 8-8). Producibility studies were based on preliminary design information and rough-order-magnitude (ROM) estimates from suppliers. Cost summaries thus developed were relative and, therefore, were used only as an index of measurement. Nevertheless, tradeoff studies provided the basis for the elimination of those configurations which showed a large cost differential, such as that utilized for roll-extruded barrel sections offered by the Ladish Company, (A3, Fig. 8-8). Analysis on the 7 tank configurations shown in Fig. 8-8 narrowed the selection to 3 candidates, one for each combination of material and joining process. Of the 3 fusion-

Table 8-3

FUSION-WELD — CYLINDRICAL BODY

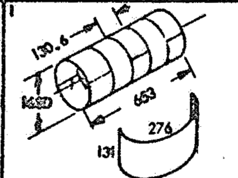
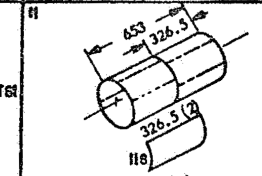
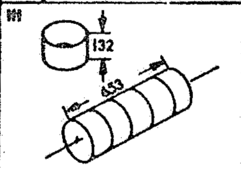
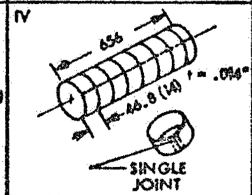
MAT'L	GEOMETRY	NO. OF PARTS	STOCK SIZE (IN.) AND WT. (LB)	PROCESS STEPS	WELD (IN)	MAJOR TOOLING	FABRICATION COST PER TANK $		NOTES
2219-T81	I  (ROLLED PANELS)	10	.125 x 132 x 276 EA. 470 LB EA. Σ W = 4700 (2460 LB)(1)	• ROLL FORM • TRIM • CHEM-MILL • RE-SIZE • CLEAN & DRESS EDGES • WELD CYLIN. (L) • TEST WELD • SIZE SECTIONS • DRESS EDGES • WELD CYL-CYL (Φ) • TEST WELD	L = 1318 Φ = 2111 Σℓ = 3429 (5018)(1)	• HANDLING FIXT. • TEMPLATES/MASKS • ROUT FIXT. • L-WELD FIXT. • Φ-WELD FIXT. • SIZING FIXT.	• MAT'L • FAB • CHEM-MILL • WELD	6,350 850 1,260 10,300 18,760 (20,510)(1)	(1) USING 84 IN. WIDE SHEET STOCK
2219-T81	II  (ROLLED PANELS)	10	.125 x 118 x 330 500 LB EA. Σ W = 5000 (2580 LB)(1)	SIMILAR TO ABOVE	L = 3295 Φ = 528 Σℓ = 3823 (5149)(1)	• HANDLING FIXT. • TEMPLATES/MASKS • ROUTING FIXT. • L-WELD FIXTURE • Φ-WELD FIXT. • SIZING FIXT.	• MAT'L • FAB • CHEM-MILL • WELD	6,750 1,050 1,260 11,500 20,500 (21,245)(1)	(2) MAX. CAPABILITY AVAILABLE IS 455 IN. WIDE
2219-T87	III  (ROLL EXTRUSION)	5	.100 x 168 x 132 700 EA. Σ W = 3500 • WITH INTERNAL RIBS	• ROLL EXTRUDE BARRELS • FINAL CHEM-MILL • SIZE ENDS • DRESS EDGES • Φ - WELD • TEST WELD	L = O Φ = 2111 Σℓ = 2111	• ROLL FORM TOOLING • SIZING FIXT. • MASKS • Φ-WELD FIXT.	• PURCHASED CYLINDERS • CHEM-MILL • WELD • SHIPPING	138,500(3) 12,000 6,330 10,000 156,830	(3) BASED ON LADISH CAPABILITY & ESTIMATES PROCESS DEV. REQ'D.
301 XFH	IV 	14	.014 x 48 x 527 (14) SKIN 1543 MISC. 9 Σ = 1558	• WELD BARREL • SP. WLD DOUBLER • FIT BARRELS • CIRC. SP. WLD. • ROLL SEAM WELD • DRAIN & DRY	FUSION - 659 SEAM - 6850 SP. WLD - 15,020 Σ ℓ = 22,529	• FUSION WELD FIXT. • HOLDING RINGS • SP. WLD. FIXT. • SEAM WLD. FIXT. • ASSY FIXT.	• MAT'L • FAB • WELDING • CLEAN & DRY	1,700 280 29,900 320 32,200	EQUIPMENT DEVELOP. REQ'D. NO PROCESS DEVELOPMENT REQ'D.

Table 8-4

WELD-BOND — CYLINDRICAL BODY

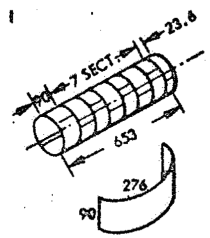
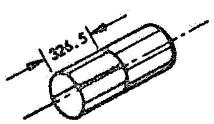
MAT'L	GEOMETRY	NO. OF PARTS	STOCK SIZE AND WT. (LB)	PROCESS STEPS	WELD (IN.)	MAJOR TOOLING	FAB. COST PER TANK $		NOTES
2219-T81	I  (ROLLED PANELS)	16	.045 x 84 x 274 (14) .045 x 66 x 276 (2) SKIN 1665 DOUB. 110 Σ W 1775	• FAB FRAME & SKIN • PRECLEAN • APPLY ADHESIVE • INSTALL SKINS • TACK WELD • SPOT WELD • CLEAN OFF • CURE • TEST BOND	L = 1308 Φ 3700 Σ ℓ 5008 (BOND LINE)	• HANDLING FIXT. • TEMPLATES • FRAME JIG • SP. WLD. FIXT.	MAT'L FAB WELD/TEST	2,500 2,450 15,050 20,000 (1) (20,600)	(1) USING .125 x 135 SHEET & CHEMICAL TO THICKNESS
2219-T81	II  (ROLLED PANELS)	16	.045 x 84 x 330 (16) 1860 DOUBLER 130 Σ W = 1990	SIMILAR TO ABOVE	L = 5270 Φ 527 Σ ℓ ≈ 5800	• HANDLING FIXT. • TEMPLATES • CAGE JIG • SP. WELD FIXT.	MAT'L FAB WELD/TEST	2790 2560 17,400 22,750	• OVER 350" THROAT REQ'D. FOR SP. WLDR.
XPH-301	NOT CONSIDERED								

Table 8-5

FUSION-WELD AND WELD-BOND — AFT DOME

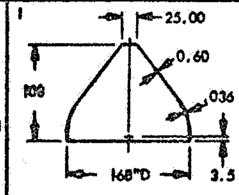
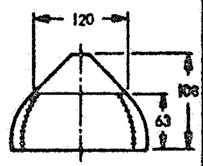
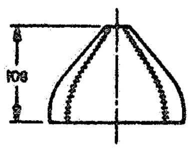
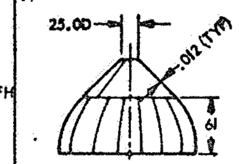
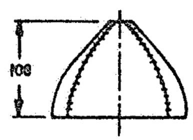
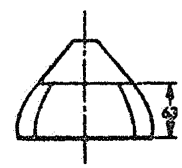
	MAT'L	GEOMETRY	NO. OF PARTS	STOCK SIZE (IN.) AND WT. (LB)	PROCESS STEPS	WELD (IN.)	MAJOR TOOLING	FAB. COST PER TANK	$	NOTES
FUSION WELD	2219-T81	I  (SHEAR FORM)	1	.25 x 200 D (1) Σ ℓ = 810	• MACHINE PREFORM • 1ST SHEAR FORM • SOLU HT. TR. • FINAL SHEAR FORM • AGE • CHEM-MILL	0	• TRACER TEMPLATE • FORMING MANDRELS • HT. TR. FIXTURE • HANDLING FIXT. • SHIPPING FIXT. • CHEM-MILL TEMPLATE • CHEM-MILL FIXT.	DOME + MAT'L CHEM-MILL	5,000 900 5,900	(1) F-TEMPER SOME PROCESS DEVELOPMENT MAY BE REQUIRED
	2219-T81	II  (SPIN/STRETCH FORM)	5 1 CONE 4 GORES	.102 x 76 x 163 (4) .125 x 130 x 130 520 264 Σ W = 784	• SPIN CONE & TRIM • STRETCH FORM GORES • TRIM GORES • CHEM-MILL • WELD ASSEM. • TEST WELD	L = 280 Φ = 380 Σ ℓ = 660	• SPIN BLOCKS • STRETCH BLOCKS • TRIM FIXTURE • TEMPLATES • CHEM-MILL MASKS • WELD FIXTURES	MAT'L SPIN CONE FAB CHEM-MILL WELD/TEST	1100 410 450 1920 2000 4880	NO PROCESS DEVELOPMENT REQ'D
	2219-T81	III  (EXPLOSIVELY SIZED CONICAL WELDMENT)	4	22/132 x 130 x .103 (4) Σ W = 420	• CUT BLANKS • ROLL CONE SEGMENTS • CHEM-MILL • WELD CONE • EXPLOSIVELY SIZE	L = 440 Φ = 0 Σ ℓ = 440	• TEMPLATES • WELD FIXT. • EXPLOSIVE DIES • CHEM-MILL MASKS	MAT'L FAB CHEM MILL	590 4000 1100 5690	SOME PROCESS DEV. MAY BE REQ'D

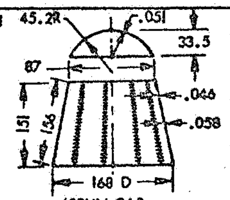
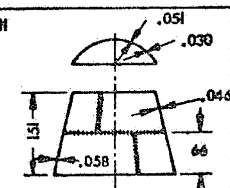
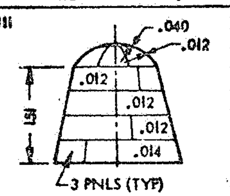
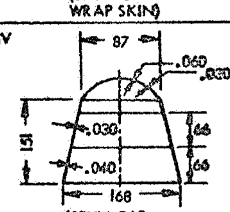
Table 8-5 (Cont'd)

	MAT'L	GEOMETRY	NO. OF PARTS	STOCK SIZE (IN.) AND WEIGHT (LB)	PROCESS STEPS	WELD (IN.)	MAJOR TOOLING	FAB COST PER TANK	$	NOTES
FUSION WELD	301-XFH	IV 	15 13 GORE 2 PNL	.012 x 48 (50/200) - 2 .012 x 70 x 76 - 13 Σ W = 260	• CUT BLANKS • ROLL CONE PNL • WELD CONE • FORM GORE • WELD GORE • WELD CONE TO BASE	L = 1004 ϕ 376 Σ ℓ = 1380	• STRETCH BLOCKS • TRIM FIXTURES • CONE WELD FIXT. • BASE WELD FIXT. • TEMPLATES	• MAT'L • FAB • WELD/TEST • CLEAN/DRY	300 480 5400 200 6,380	NO PROCESS DEV. REQ'D.
FUSION WELD	301-XFH	V  (EXPLOSIVELY SIZED CONICAL WELDMENT)	11	.030 x 48 x 130 (11) Σ W = 550	SAME AS III	L = 1220 ϕ 0 Σ ℓ = 1220		MAT'L FAB CHEM-MILL	600 6250 2500 9,350	MAY NOT DEV. XTR FULL HARD PROPERTIES PROCESS DEV. REQ'D
WELD-BOND	2219-T81	VI 	7 1 CONE 6 GORE	.180 x 139 x 130 (1) .048 x 76 x 118 (6) Σ W = 570	• SPIN CONE • STRETCH GORE • FAB FRAME • JOIN GORES • JOIN CONE	L = 400 ϕ 380 Σ ℓ = 780	• SPIN BLOCK • STRETCH BLOCK • TRIM FIXT. • TEMPLATES	• MAT'L • CONE • FAB GORES • CHEM-MILL • WELD/TEST	[illegible] 410 2,000 1,100 2,300 6,680	NO PROCESS DEV. REQ'D.
WELD-BOND	[illegible] S.S.	NOT CONSIDERED FOR WELD BOND								

B-5(...)

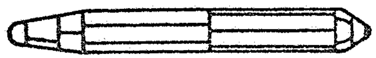
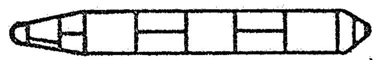
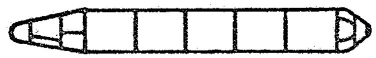
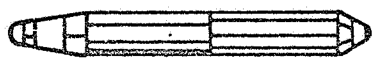
Table 8-6

FUSION-WELD AND WELD-BOND — FORWARD DOME

	MAT'L	GEOMETRY	NO. OF PARTS	STOCK SIZE (IN.) AND WEIGHT (LB)	PROCESS STEPS	WELD (IN.)	MAJOR TOOLING	FAB COST PER TANK $		NOTES
FUSION WELD	2219-T81	I  (SPUN CAP ROLLED PANELS)	8 1 CAP 7 PNLS	.125 x 130 x 130 = 1225 .100 x 84 x 156 = 950 Σ W = 1175	• SPIN CAP • CHEM-MILLS • ROLL CONICAL SEGM. • TRIM CONIC. SEGM. • CHEM-MILL C-SEG. • WELD CONIC FRUSTUM • WELD CAP/CONE • TEST WELDS	L = 1092 ϕ = 274 Σℓ = 1,366	• SPIN BLOCKS • TEMPLATES • ROUT. FIXT. • CHEM MILL MASKS • WELD FIXTURES	• MAT'L • SPIN CAP • FAB • CHEM-MILL • WELD/TEST	1640 410 385 790 4100 7325	NO PROCESS DEVELOP. REQ'D
FUSION WELD	2219-T81	II  (SPUN CAP ROLLED PANELS)	6 1 CAP 5 PNLS	.125 x 130 x 130 = 225 .100 x 84 x 276 = 480 .100 x 84 x 152 = 393 Σ W = 1098	• SPIN CAP • CHEM-MILL CAP • ROLL CONIC SEGMENTS • CHEM MILL C-SEG. • WELD CONIC FRUSTUMS • WELD FRUSTUMS • WELD ASSY-CAP • TEST WELD	L = 398 ϕ = 689 Σℓ = 1,087	• SPIN CHUCK • TEMPLATES • ROUTE FIXTURES • CHEM. MILL MASKS • WELD FIXTURES	• MAT'L • SPIN CAP • FAB • CHEM-MILL • WELD & TEST	1540 410 320 600 3300 6170	NO PROCESS DEVELOP. REQ'D
FUSION WELD	301 XFH	III  (SPUN CAP WRAP SKIN)	13 1 CAP 12 PNLS	.040 x 130 x 130 = 200 .014 x 48 x L (12) = 340 Σ W = 540	• SPIN CAP • CHEM-MILL CAP • TRIM CONICAL PATTERN • FAB FRUSTUMS • JOIN FRUSTUMS • JOIN SKIRT • JOIN FRUSTUM-CAP	L = 468 ϕ = 2000 Σℓ = 2468	• SPIN CHUCK • HT. TR. FIXT. • TEMPLATES • CHEM-MILL MASK • WELD FIXT.	• MAT'L • FAB CAP • CHEM-MILL CAP • WELD/TEST • CLEAN/DRY	600 510 260 9600 200 11,370	NO PROCESS DEVELOP. REQ'D
WELD BOND	2219-T81	IV  (SPUN CAP ROLLED PANELS)	7 1 CAP 6 PNLS	.125 x 130 x 130 .030 x 29 x 32 (2) .045 x 84 x 275 (2) .045 x 84 x 220 (2) Σ W = 640	• SPIN CAP • CHEM-MILL CAP • CVT BLANKS • ROLL FORM • SP. WELD FRUSTOM	L = 312 ϕ = 1,000 Σℓ = 1,312	• SPIN CHUCK • TEMPLATES • ROUTE FIXT. • CHEM-MILL MASK • ASSY FIXT. • SP. WLD FIXT.	• MAT'L • CAP • CHEM-MILL CAP • FAB • WELD/TEST	950 410 230 1,180 3,950 6,720	NO PROCESS DEV. REQ'D.

LOCKHEED

TANK CANDIDATE CONFIGURATIONS

			MATERIAL	CYLINDER WELD LENGTH (INCHES)			TANK WEIGHT (LB)	REMARKS
FUSION WELDED	A-1		ALUMINUM 2219	LFW CFW	3,270 527	3,797	2557	SKT 100710 SKT 100702
	A-2	 ★		LFW CFW	1,308 2,110	3,418	2555	SKT 100707
	A-3			LFW CFW	0 2,110	2,110	2550	
	C-1	 ★	301 XFH	LFW LSW CFW CSW	658 1,286 6,851 13,702	22,497	2392	STOVE JOINT SKT 100711
	C-2		301 XFH	SAME AS C-1				BUTT JOINT
WELD-BONDED	B-1		ALUMINUM 2219	LSW CSW	18,144 2,108	20,252	2450	SKT 100704
	B-2	 ★		LSW CSW	5,232 14,756	19,988	2440	SKT 100708

LFW = LONGITUDINAL FUSION WELD
CFW = CIRCUMFERENTIAL FUSION WELD
LSW = LONGITUDINAL SPOT WELD
CSW = CIRCUMFERENTIAL SPOT WELD

★ SELECTED TANK DESIGNS

D03558 (1)

Fig. 8-8

welded aluminum designs, Concept A-2 was selected on the basis of shorter weld length and lowest cost. Although A-3 using extruded barrel required the shortest weld length, it was rejected due to excessive cost, more than double that of A-2. Of the two stainless steel configurations, C-1 using the "stove-pipe" joining concept, a design well-qualified by Atlas/Centaur performance, was selected. Of the two weld-bond aluminum designs, B-2 was selected on the basis of shorter weld length, lighter weight, and lower cost.

These three configurations — called baseline configurations — are used for a detailed design and manufacturing analysis to establish a realistic droptank baseline program cost estimate. The three configurations selected are noted with a star in Fig. 8-8. They are:

- Configuration A — Fusion-welded 2219 aluminum alloy
- Configuration B — Weld-bonded 2219 aluminum alloy
- Configuration C — Fusion-welded extra-full-hard 301 stainless steel

Section 9
BASELINE DESIGN CONFIGURATIONS

Utilizing the three baseline configurations selected in the producibility analysis tasks, detailed design layouts, weight estimates, and supporting analyses were performed and all essential subsystems defined and integrated into three formal tank system designs. These designs are described below.

9.1 BASELINE CONFIGURATION A

This tank arrangement is shown in Design Drawing SKT 100707 (Fig. 9-1). The assembly is primarily one that employs fusion welding throughout the pressure vessel areas with weld bonding used only for attachment of the tank attach skirt located at the forward end of the tank cone. Material of construction used throughout the tank is primarily 2219-T81 aluminum alloy. Process and fabrication control specifications are as listed in notes on the drawing.

The tank assembly generally consists of a cylinder, forward cone, a forward tank end, and an aft tank end.

The tank cylinder is constructed from five (5) barrel sections. Each barrel is approximately 130 inches wide and consists of two panels, each chemically milled to the required membrane thickness, then roll-formed and butt-welded together. Weld land thicknesses, seventy (70) percent greater than the membrane thicknesses, are provided around the edges of each panel to permit an adequate butt-welded joint. The five barrel sections are butt-welded together to form the basic cylinder length of approximately $54\frac{1}{2}$ feet. Tank inside diameter in the cylinder area is fourteen (14) feet. Membrane thickness varies from 0.057 in the forward barrel section to 0.053 in the most aft barrel section. These thicknesses consist of the minimum thickness required structurally (pressure) and tolerance allowances for chemical milling (.003) and the raw material (.010).

The tank forward cone consists of 2 fifteen (15) degree conical sections. The forward section is made up from three (3) panels, chemically milled in the flat pattern and then roll-formed to shape and butt-welded to constitute the cone section. The aft section is similarly constructed from two (2) panels. The attachment between the tank forward cone and the cylindrical section is made by butt welding to a roll-formed T-section ring adequate to resist kick loads introduced at the transition corner.

A spun and then chemically milled dome constitutes the forward tank end. This dome is approximately seven (7) feet in diameter (3.77 foot spherical radius) and is butt welded to the tank forward cone section. A thirty (30) inch diameter and a ten (10) inch diameter cutout is made in the dome to receive machined elements containing machined surfaces for the tank access cover and a vent line connection,respectively. The elements are butt-welded to the dome. The machined surfaces have been machined to accept a conoseal as well as the bolt holes for connecting the cover and piping.

The aft tank end consists of a spherical zone, aft cone, and dome. The spherical zone is made up from four (4) stretch formed gore panels formed around an 84-inch spherical radius. Each gore panel is chem-milled to a membrane thickness of 0.036 inches. A tapered weld land is provided to match adjacent areas of the tank to which the gore panels will be welded. The gore panels are initially butt welded together to form the spherical zone section. This section is butt welded to the aft cone which is a spin formed part chem-milled to provide a membrane thickness of 0.060 inches. Propellant line connections, similar in design as those described on the forward tank end, are provided on the aft cone section. These propellant line connections consist of a feed line (16-inch-diameter) and a recirculating line (3-inch-diameter). The aft dome is also a machined element butt welded to the aft cone. This dome as well as the pipe outlet elements contain the mounting bolts and/or conoseal surfaces necessary to make the appropriate connections. The complete aft tank end assembly is butt-welded to the aft end of the tank cylindrical section.

Design Drawing SKE 100720 (Fig. 9-2) shows a general arrangement of an installation of a typical external LH_2 droptank system employing a tank arrangement as described in this section. The following typical subsystems and elements are shown:

- Tank-to-Orbiter Attachment System
- Nose Fairing Cone Assembly
- Retrorocket System
- Propellant System Lines
- Instrumentation
- Electrical System
- Droptank System Insulation

At the forward end of the tank, three support fittings extend radially from a bulkhead just in front of the tank dome. The forward support members consist of a single tension rod and two compression struts. The tension rod is connected to the orbiter structure by an explosive separation bolt with suitable length adjustment threads. A U-joint between the explosive bolt and the tension rod minimizes bending loads on the bolt. The compression strut-ends are lodged in sockets on the orbiter and held in place by preloading the tension rod. Activation of the tension rod separation device releases the entire forward support system from the orbiter.

At the aft end, the three support struts are attached to the tank through a single fitting. All struts are attached to the orbiter by separation bolts similar to the forward separation system.

The lower radial support struts, both forward and aft, contain the tank ejection actuators. A gas generator within the strut drives a piston which moves the tank away from the orbiter when the separation system is activated.

Design Drawing SKM 100717 (Fig. 9-3) illustrates the baseline assembly for the droptank system nose fairing. The fairing provides protection and support for the forward end tank plumbing, the bulk of the electrical subsystem, and the propulsion system instrumentation located on the forward end of the LH_2 tank. The nose fairing cone assembly is mounted on the forward tank skirt and consists of a cone assembly and dome section assembly. The cone section is constructed of magnesium and the dome section is constructed of laminated sitka spruce. The cone section consists of an aft and forward truncated cone. Each cone consists of an integrally stiffened skin riveted to end rings. The rings are rolled extrusions (AS 31B) butt fusion-welded to form the circular element. The rolled skins are fabricated from HM 21A magnesium alloy plate butt fusion-welded to form a cone having a single longitudinal welded joint. The integral rings are chem-milled after the cone is made. Ring spacing increases toward the forward end. The forward cone contains two (2) diametrically opposite doors that provide access to the equipment and instrumentation for installation and maintenance. Skin cutouts are reinforced by chem-milling integral frames around these cutouts. Curved plate doors are attached to the frame structure with titanium screws and stainless steel self-locking anchor nuts. The dome section assembly consists of a jettisonable cap and fixed (mechanically attached) partial dome.

The nose cone assembly incorporates the mounting structure for the retrorocket, electrical equipment, tank instrumentation and forward tank to orbiter attach struts. This substructure is fabricated from magnesium alloy.

A retrorocket system is installed on the forward end of each droptank system and is attached to the nose cone fairing substructure also shown in Drawing SKM 100717 (Fig. 9-3).

The tank propellant system schematic (see Fig. 9-2) shows all tank-mounted plumbing and the propellant system interface with the orbiter.

The pressure line and the vent line which originate in the tank forward dome are mounted on the outer surface of the tank and connected to the orbiter pressure and vent systems of the tank/orbiter interface. The propellant feedline and the recirculation line enter the tank near the rear dome. These lines, as well as the pressure and vent lines, are insulated as shown in Section C-C.

Fourteen optical liquid sensors are deployed along the tank wall from the tank bottom to a tank station about 75 in. below the top dome. An additional four sensors are placed around the circumference at this location, and four more in the vicinity of the propellant feedline outlet. The sensors are mounted on the tank wall, as shown in Section G-G (Fig. 9-2).

Propellant temperature is monitored by temperature transducers inserted in the propellant feedline and recirculation line, shown in Detail J, and four transducers located near the upper tank dome.

Tank pressure is measured by four pressure transducers mounted on the upper manhole cover, Detail H.

During tank separation, distance from the orbiter is measured by two tapes, which are payed out as the tank separates. (See Section 13 for a description of the instrumentation required for this function.)

The electrical system is located mainly on the nose fairing bulkhead in front of the tank forward dome. It consists of batteries, power transfer controls, timer, and transister logic.

The tank is insulated by a composite insulating system consisting of cork, polyurethane foam, adhesives and sealers, as shown in View F of Fig. 9-2.

9.2 BASELINE CONFIGURATION B

The method of construction where weld bonding is primarily used is illustrated in Design Drawing SKT 100708 (Fig. 9-4). Material of construction used throughout the tank is 2219-T87 aluminum alloy. Process and fabrication control specifications are as listed in the notes on the drawing.

The tank assembly generally consists of a cylinder, forward cone, a forward tank end, and an aft tank end. A tank skirt is also weld-bonded to the forward end of the tank cone.

The basic approach to the assembly of this concept is the construction of a frame system (doublers), fusion-welded together to form a cage-like arrangement upon which appropriate roll-formed panels are attached. This form of construction extends from the forward end of the forward cone back to the aft end of the spherical zone segment of the aft tank end. The cylindrical section consists of eight (8) barrel-like sections, seven (7) of which are seven (7) feet in width (available sheet sizes) and the eighth section only 65 inches wide.

Each cylindrical section is made up from two panels of stock size sheets. The tank forward cone is constructed from three conical sections made up from two panels of stock size sheets. The spherical zone segment portion of the aft tank end is constructed from six (6) stretch-formed gore panels formed about an 84-inch spherical radius and then weld-bonded to the spherical frame (doubler) system. The doubler system is constructed from flat stock of appropriate thickness except at two places. The joint between the forward cone and the cylindrical section uses a roll-formed T-section in the framing and the joint between the forward and mid conical sections of the forward cone uses a chem-milled ring strap doubler having a weld land to provide for the tank-closure fusion-weld necessary at this tank station. All panel attach joints are a combination adhesive and double spot-resistance weld arrangement as shown on the drawing.

A spun dome constitutes the forward tank end. This dome is chem-milled down to provide a membrane thickness of 0.030 inch and is similar to the dome described in Configuration A. The basic change is that this dome is weld-bonded to the frame (doubler) system provided at the forward end of the forward cone section.

The aft cone and dome elements of the aft tank end section are similarly constructed as described for Configuration A, with the exception that the aft cone is weld-bonded to the frame system provided at the aft end of the spherical zone segment.

9.3 BASELINE CONFIGURATION C

The use of a stainless steel material for construction in a typical LH_2 droptank system is shown in Design Drawing SKT 100711 (Fig. 9-5). Process and fabrication control specifications are as listed in the notes on the drawing.

The general approach to the construction in this design is the use of a combination fusion welded plus resistance seam and spot welded arrangement. The tank assembly consists of a cylinder, forward cone, a forward tank end, and an aft tank end. A tank skirt is also weld-bonded to the forward end of the tank cone.

The tank cylinder consists of fourteen (14) equally spaced barrel sections, with each barrel made from 0.014-inch thick coil stock, formed into a fourteen (14) foot inside-diameter circle and fusion-butt-welded with a flat-stock doubler spot-welded behind the longitudinal fusion seam. The barrel sections are "stove-piped" together as shown and joined to the adjacent barrel, using a combination seam and spot-weld to provide for adequate sealing and strength.

The tank forward cone consists of four (4) conical sections with each section made up from three (3) roll-formed panels 48 inches wide and butt-welded together to form a cone. Membrane thicknesses vary from 0.012 to 0.014 inch for the aft conical section. The three aft conical sections are "stove-piped" together and joined as described for the cylinder. The forward conical section panels are formed and then chem-milled to the required membrane thickness (0.012) plus a 0.040-inch weld land thickness at the forward periphery used for the butt weld attachment of the forward tank end dome.

The attachment between the tank forward cone and the cylindrical section is made by spot and seam welding to a roll-formed T-section ring adequate to resist kick loads introduced at the transition corner and containing an arrangement of tooling holes used in conjunction with ground handling equipment to maintain the tank in tension during transport.

A spun and then chemically milled dome constitutes the forward tank end. This dome is similar to the one described in Configuration A.

The aft tank end consists of a spherical zone, aft cone, and dome. The spherical zone is made from thirteen (13) stretched-form gore panels, chem-milled to a 0.012-inch thick membrane with adequate weld lands provided to butt-weld the gores together and to the cylinder and aft cone sections. This section is butt-welded to the aft cone fabricated from two rolled-sheets joined and butt-welded together to form the cone. The cone element is chem-milled to provide the necessary weld lands and a membrane thickness of 0.012 inch. As described in the previous configurations, the basic propellant line outlets and dome parts are provided for. The complete aft tank end assembly is butt-welded to a rolled end ring containing matching tooling holes as described for the forward kick ring. The tank end assembly is spot and seam welded to the aft end of the tank cylindrical section.

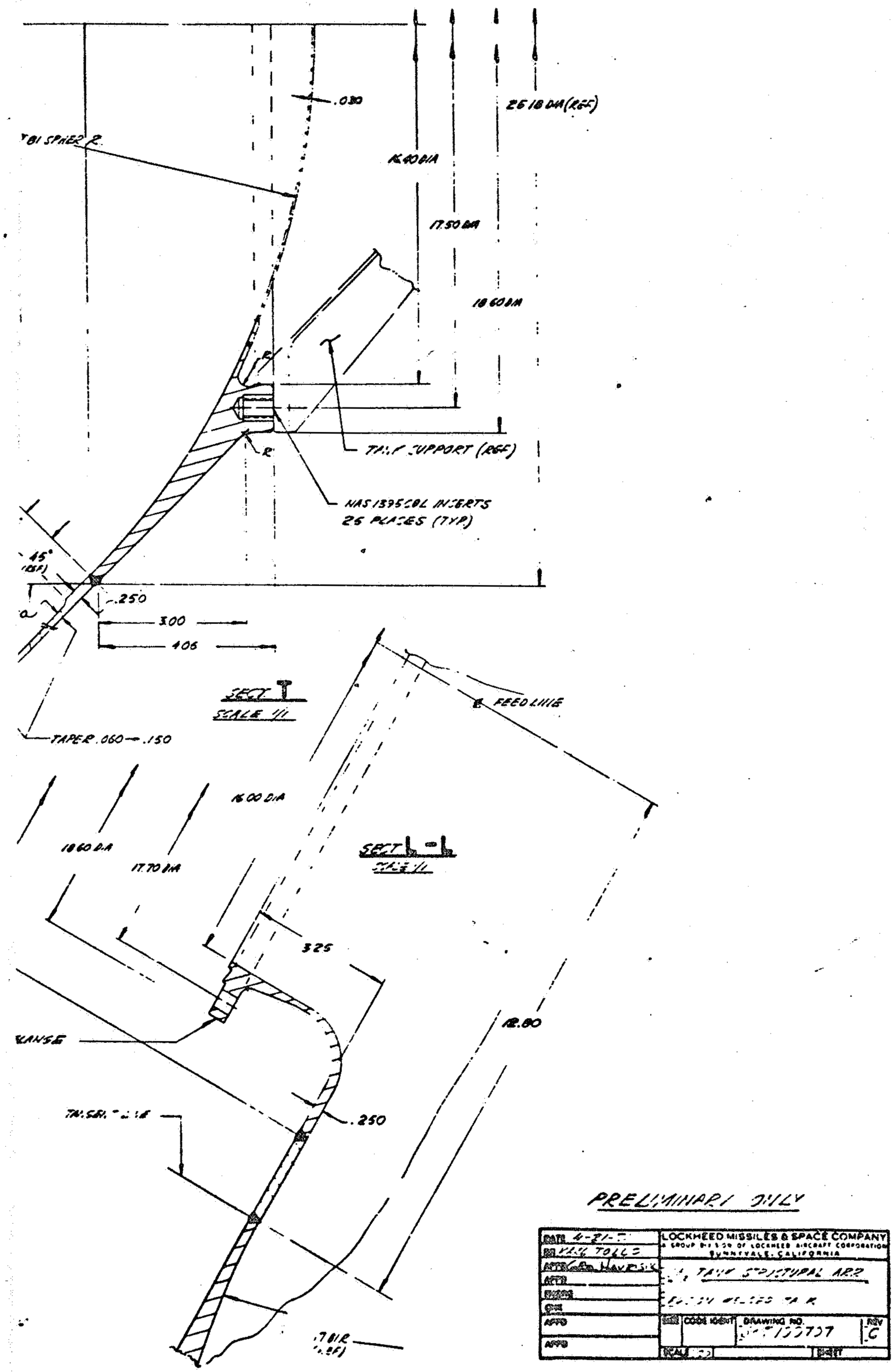
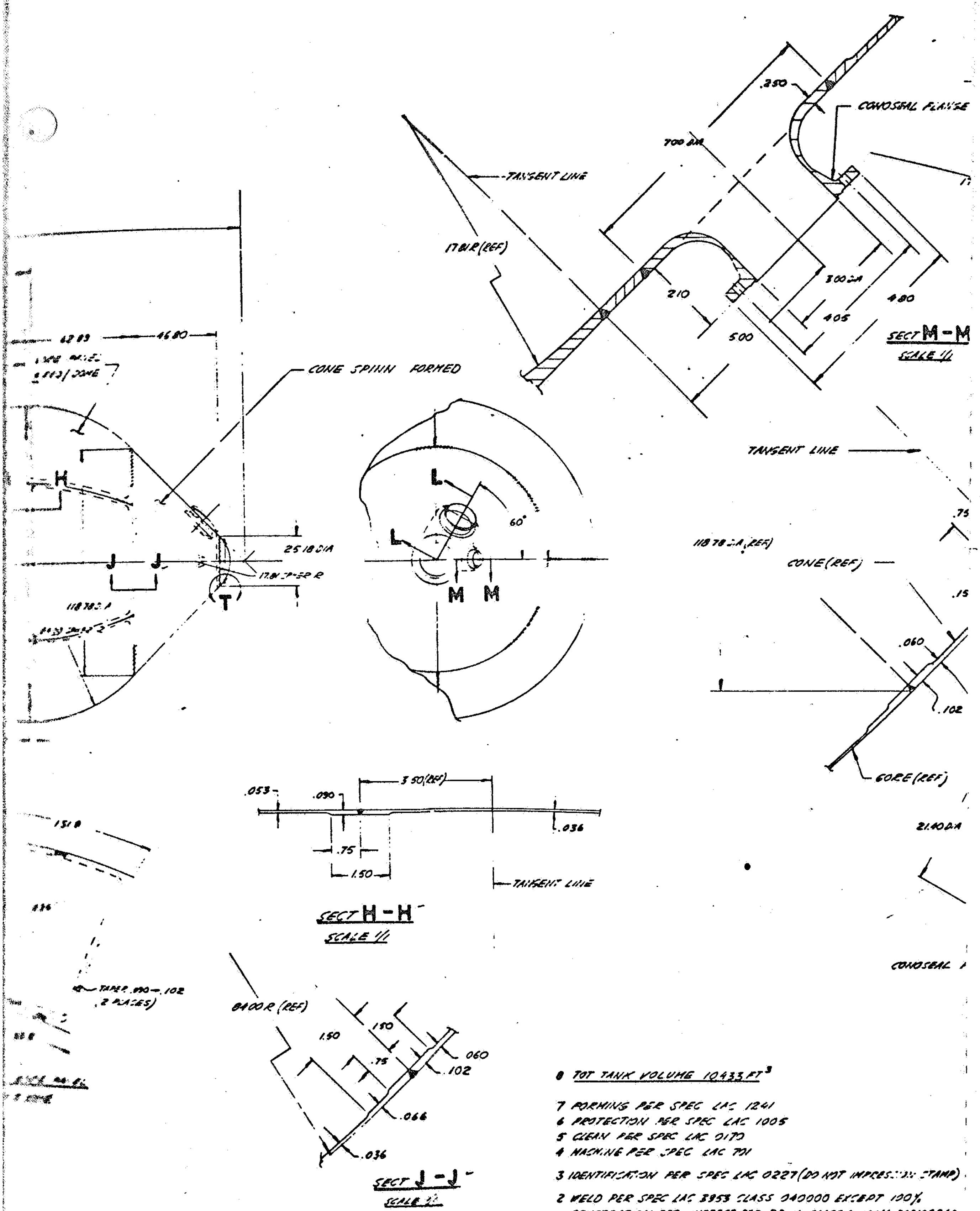


Fig. 9-1 LH_2 Tank Structural Arrangement

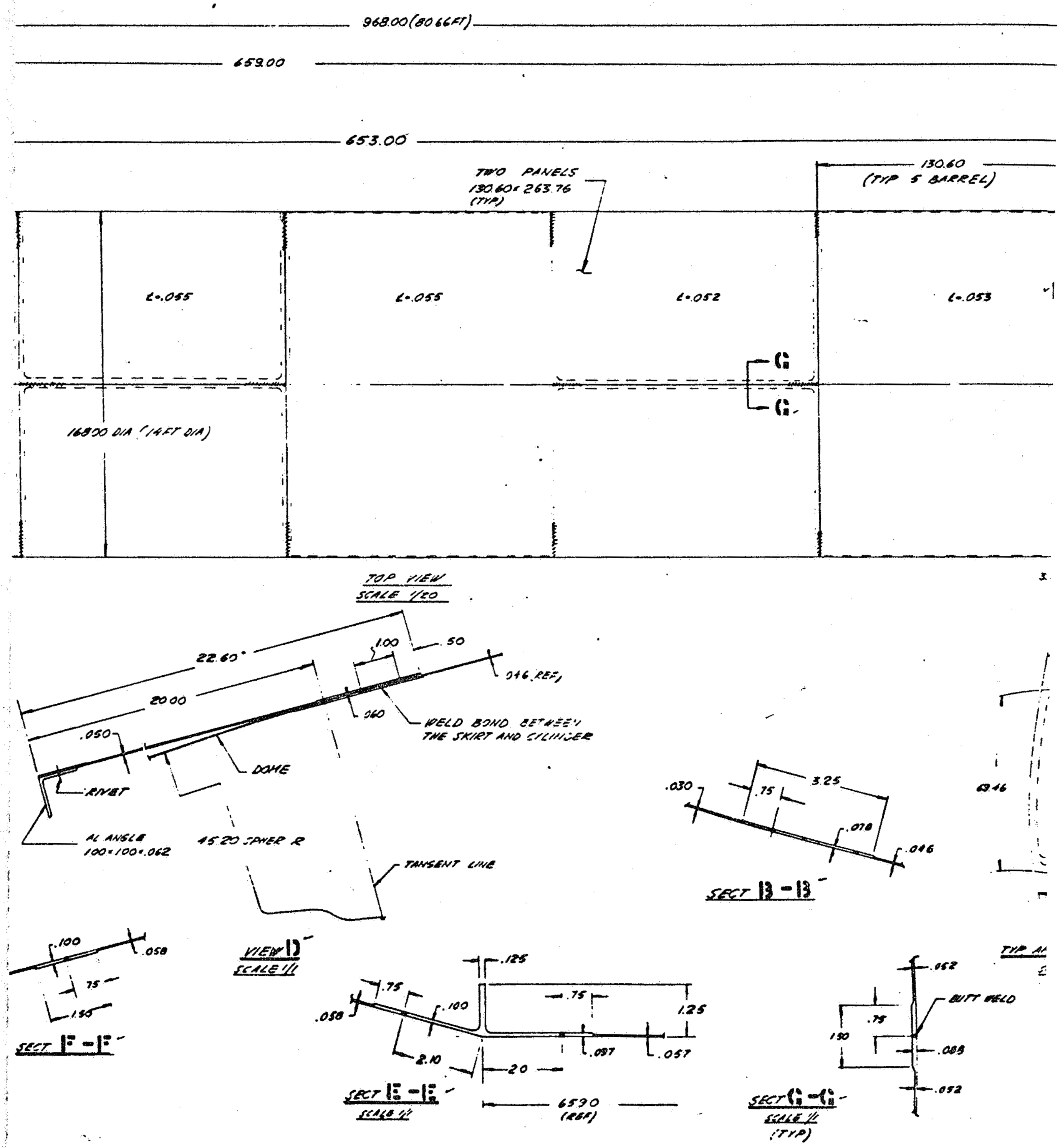


8 TOT TANK VOLUME 10433 FT³

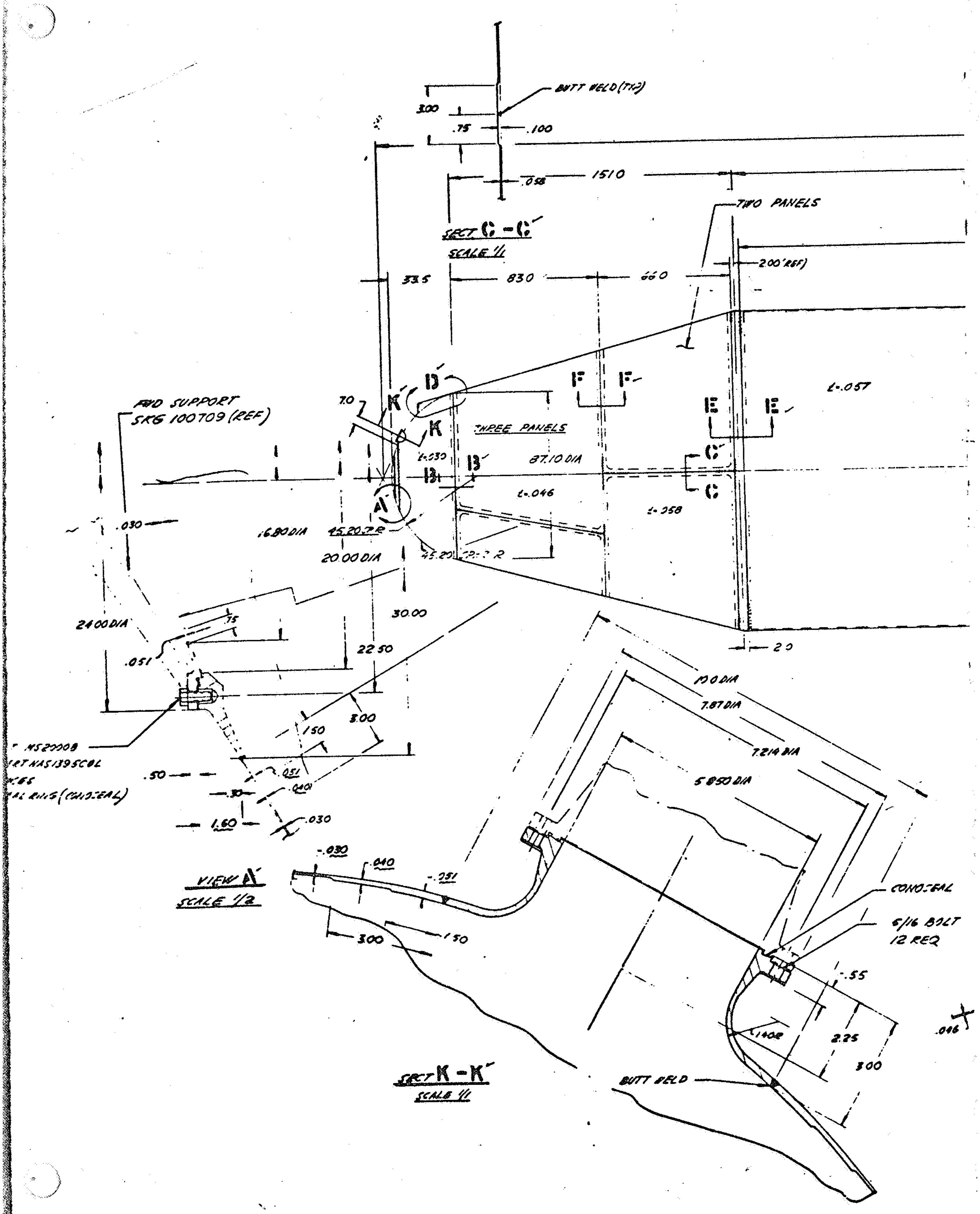
7 FORMING PER SPEC LAC 1241
6 PROTECTION PER SPEC LAC 1005
5 CLEAN PER SPEC LAC 0170
4 MACHINE PER SPEC LAC 701

3 IDENTIFICATION PER SPEC LAC 0227 (DO NOT IMPRESSION STAMP)

2 WELD PER SPEC LAC 3953 CLASS 040000 EXCEPT 100% PENETRATION REQ INSPECT PER PB-16 CLASS A, 100% RADIOGRAPH INSPECTION REQ FOR EACH PART PER LAC 0563
1 MATERIAL 2219-T81 AL ALLOY
NOTES.



968.00 (80.66 FT)
659.00
653.00
TWO PANELS
130.60 × 263.76
(TYP)
130.60
(TYP 5 BARREL)
t=.055
t=.055
t=.052
t=.053
168.00 DIA (14 FT DIA)
TOP VIEW
SCALE 1/20
22.60
20.00
1.00
.50
.046 REF
.050
.060
WELD BOND BETWEEN THE SKIRT AND CYLINDER
DOME
RIVET
AL ANGLE
1.00 × 1.00 × .062
45.20 SPHER R
TANGENT LINE
VIEW D
SCALE 1/1
.030
.75
3.25
.078
.046
SECT B-B
.100
.058
.75
1.50
SECT F-F
.125
.75
.100
.058
.75
1.25
.097
.057
2.10
.20
SECT E-E
SCALE 1/1
65.90
(REF)
.052
BUTT WELD
.75
1.50
.088
.052
SECT G-G
SCALE 1/1
(TYP)



BUTT WELD (TYP)
3.00
.75
.100
.058
15.10
SECT C-C
SCALE 1/1
TWO PANELS
2.00 (REF)
33.5
83.0
66.0
FWD SUPPORT
SKG 100709 (REF)
7.0
D
K
K
F F
E E
t-.057
THREE PANELS
t-.030
B B
87.10 DIA
C C
t-.046
t-.058
A
.030
16.80 DIA
45.20 R
20.00 DIA
24.00 DIA
.75
30.00
22.50
.051
3.00
1.50
.50
.051
.040
.30
1.60
.030
VIEW A
SCALE 1/2
10.0 DIA
7.87 DIA
7.214 DIA
5.850 DIA
.030
.040
.051
3.00
1.50
CONOSEAL
5/16 BOLT
12 REQ
.55
2.25
3.00
.046
BUTT WELD
SECT K-K
SCALE 1/1

INSTRUMENT LIST		
ITEM	SOURCE	ITEM NO
...T SENSORS (OPTICAL TYPE)	BENDIX	40
...MPERATURE TRANSDUCER	CEC	41
...ESSURE TRANSDUCER	CEC	42
...ESSURE SWITCH	...	43
...OE CONTAINER		44
...OTO TRANSISTOR		45
...MER AND TRANSISTOR ...		46
...WER TRANSFER ...		4.
...TTERIES		48

ORBITER

ISOLATION VALVE

DISCONNECT-PRESSURE

DISCONNECT-VENT

DISCONNECT-FEED

DISCONNECT-RECIRC

...HEMATIC

...WITH ISOLATION VALVE SIMILAR ...ADLEY 11397 OR RMD CC 135

...NTS SIMILAR TO SOLAR ...DE 55820

...OWNEAD TYPICAL MFG'S AND FITTINGS

...LISTS ARE MADE UP ...SINGLE TANK

... TO FOAM USING ...EPON 934/SCRIM CLOTH

... TO TANK WALL WITH ...D 109/SCRIM ADHESIVE

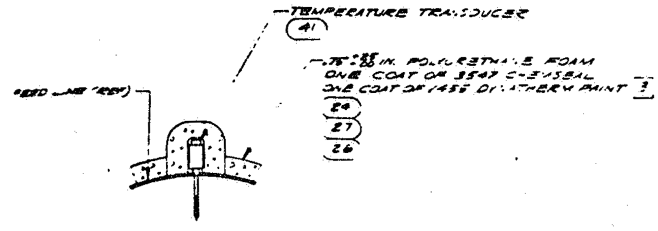
QTY	NOTE	DESCRIPTION	MATERIAL	ITEM NO
4		BELLOWS-2 IN DIA		30
		BELLOWS-14 IN DIA		29
AS REQD		LEFKOWELD 109/SCRIM ADHESIVE		28
1		CHEMSEAL 3547 COATING		27
		DYNATHERM V455 PAINT		26
		BOND EPON 934/SCRIM CLOTH		25
1		POLYURETHANE FOAM		24
AS REQD		ABLATIVE C=.30 IN	CORK	23
1		VORTEX SUPPRESSOR		22
1		VORTEX BAFFLE		21
1	6	DISCONNECT COUPLING PRESSURE		20
1	5	GIMBAL JOINT PRESSURE		19
9		CHECK VALVES 4 IN PRESSURE		18
1	4	2.0 I.D. .035 WALL PRESSURE LINE		17
1	6	DISCONNECT COUPLING, VENT		16
1		ISOLATION VALVE, VENT		15
1		RELIEF VALVE (BURST DISC), VENT		14
1		RELIEF VALVE, VENT		13
1	5	GIMBAL JOINT VENT	AL WITH INCONEL BELLOWS	12
1	4	6.0 I.D. .032 WALL VENT LINE	2219 AL	11
1	6	DISCONNECT COUPLING RECIRCULATION		10
1		ISOLATION VALVE RECIRCULATION		9
1	5	GIMBAL JOINT RECIRCULATION	AL WITH INCONEL BELLOWS	8
1	4	2.6 I.D. .028 WALL, RECIRCULATION	2219 AL	7
4		BELLOWS - 6 IN DIA		6
1	6	DISCONNECT COUPLING, FLUID LINE		5
1		ISOLATION VALVE, FLUID LINE		4
1	5	GIMBAL JOINT FLUID LINE	AL WITH INCONEL BELLOWS	3
1	4	14.0 I.D. .049 WALL FLUID LINE	2219 AL	2
1		SKT 100707 DROP TANK ASSY		1

PARTS LIST

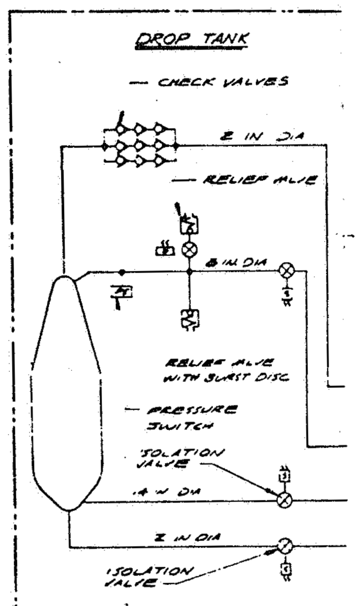
INTERPRET DWG PER	
UNLESS OTHERWISE SPECIFIED DIM ARE IN INCHES TOLERANCES ON FRACTIONS = ± 1/16 DECIMALS X = ± 1, XX = ± .03, XXX = ± .010 ANGLES = ± 2 DEG	
DATE 24 ...	DR ...
APPD / APPD / ENGRG / CHK / APPD / APPD	
CONTR / CCA.CD	
NEXT ASSY / USED ON / APPLICATION	
LOCKHEED MISSILES & SPACE COMPANY, SUNNYVALE, CALIFORNIA	
GENERAL ARRANGEMENT LH_2 DROP TANKS BASELINE	
SIZE	CODE IDENT 06887
DRAWING NO SKE 00720	REV
SCALE 1/50	SHEET 1

Fig. 9-2 General Arrangement, LH_2 Droptank Baseline

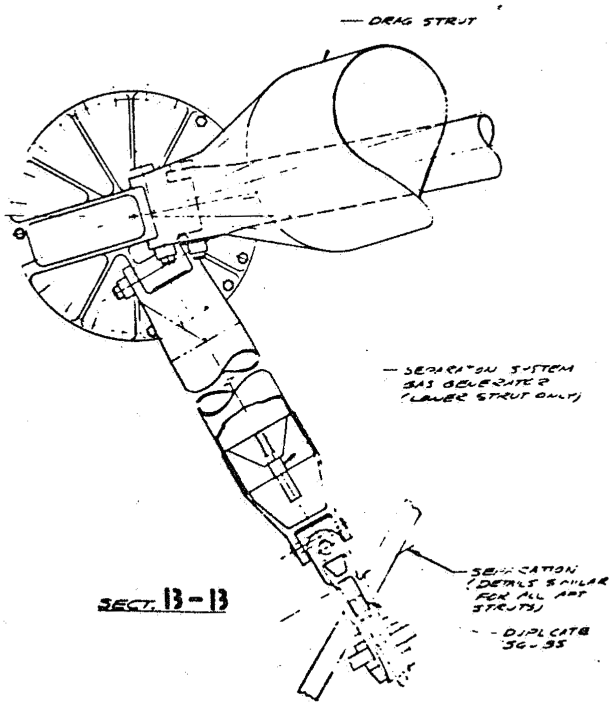
QTY	CODE	
22	●	PC...
8	□	TE...
4	○	PR...
4	[illegible]	PR...
2		TA...
2		P...
1		TI...
1		PL...
2		S...



DETAIL J
(TYP FOR FEED AND RECIRCULATION LINES)



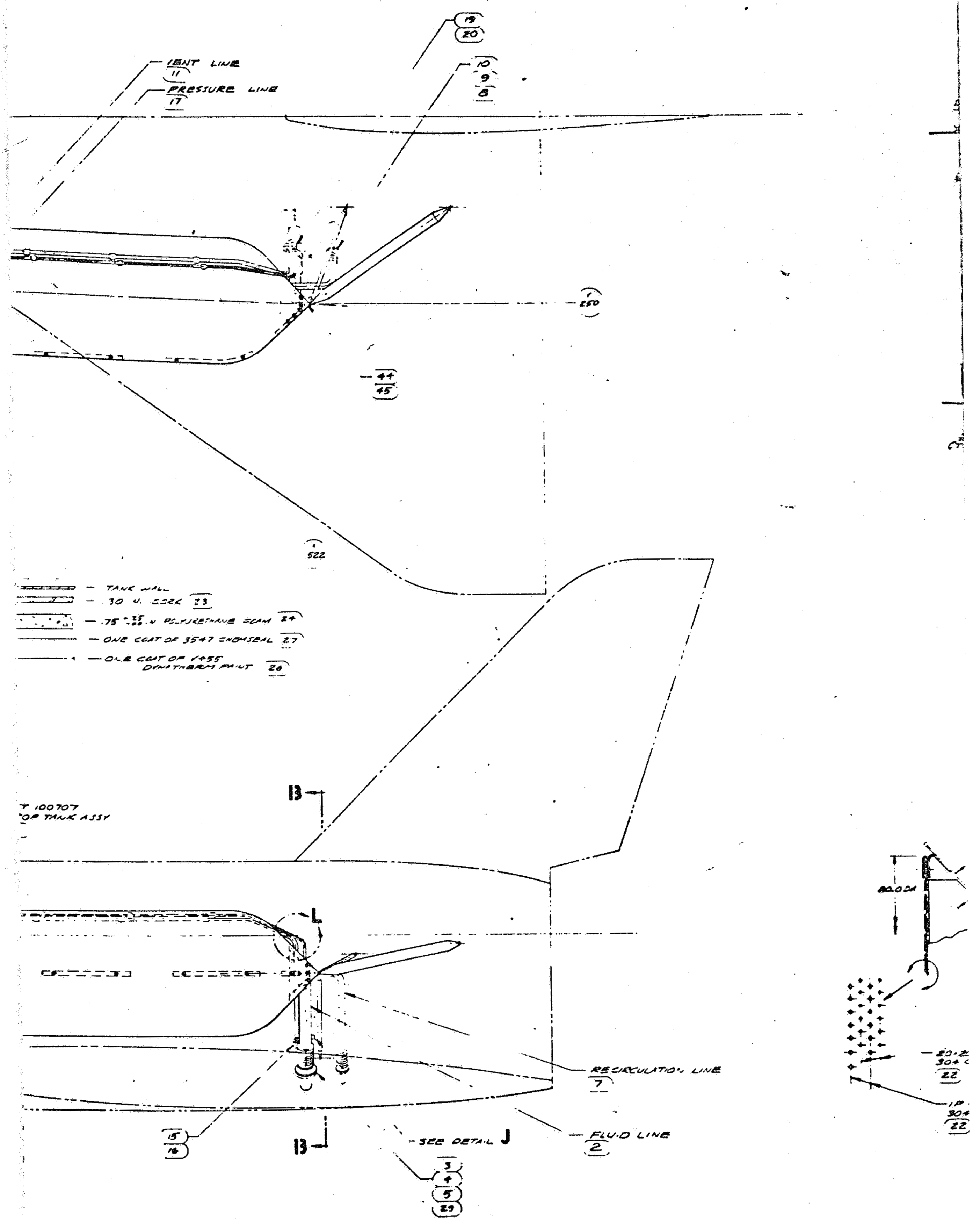
PLUMBING SC...



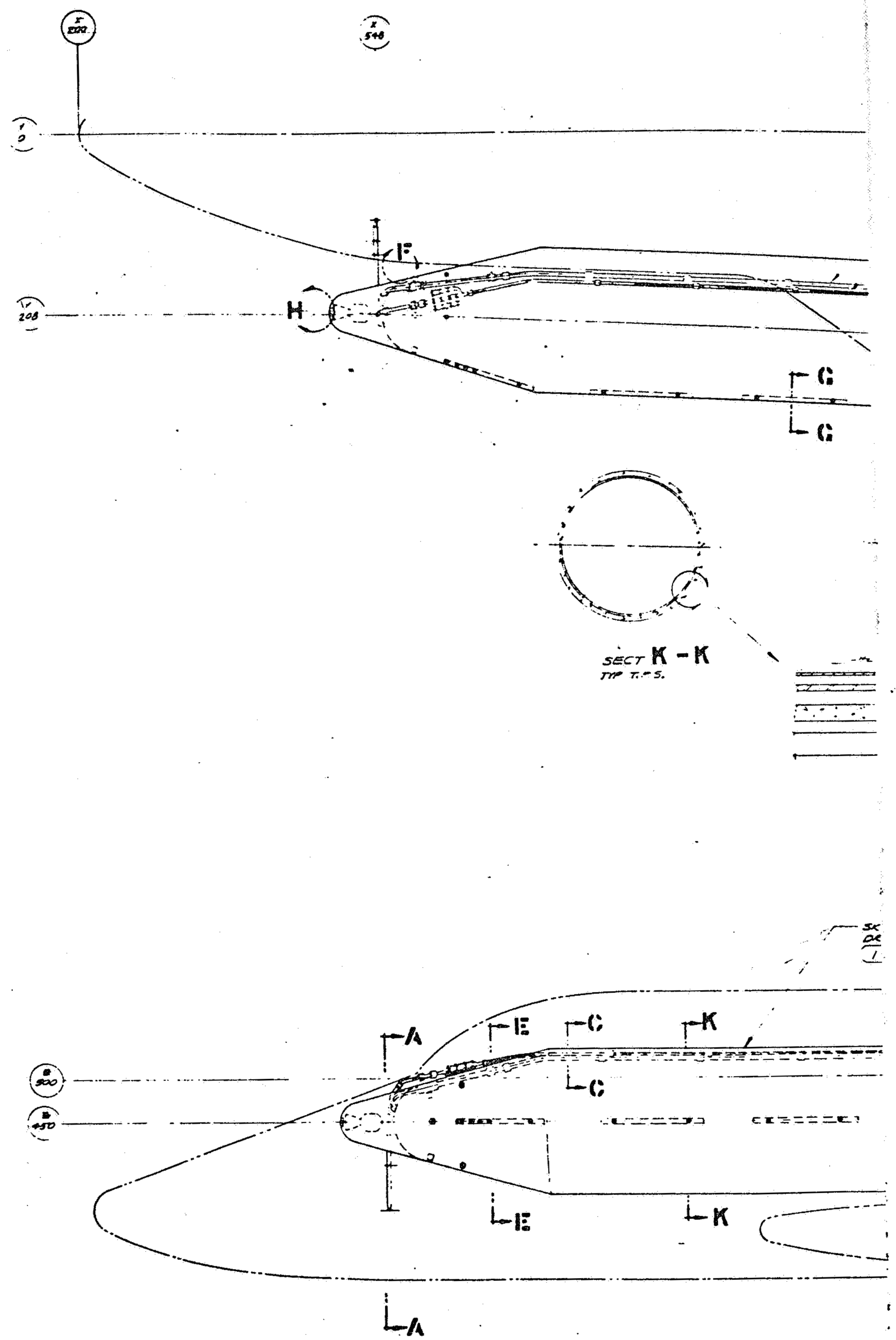
SECT. 13-13

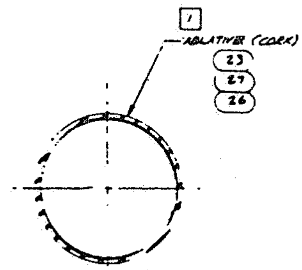
NOTES:

1. BOND CORK... LEFKOWEL...
2. BOND CORK... ADHESIVE
3. MATERIAL ... FOR ONE ...
4. SOLAR, ARR... FOR LINES
5. GIMBAL JO... 38026 CO...
6. DISCONNECT... TO ROYAL. ...

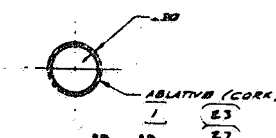


VENT LINE
11
PRESSURE LINE
17
19
20
10
9
8
250
44
45
522
TANK WALL
.30 IN CORK 23
.75 IN POLYURETHANE FOAM 24
ONE COAT OF 3547 CHEMSEAL 27
ONE COAT OF V455 DYNATHERM PAINT 26
T 100707
OP TANK ASSY
B
L
RECIRCULATION LINE
7
FLUID LINE
2
15
16
SEE DETAIL J
3
4
5
29
80.0 DIA
22
22

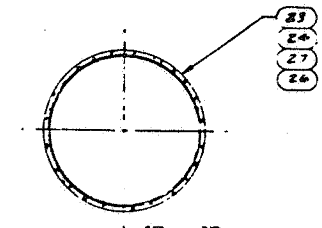

F
H
G
G
SECT K - K
TYP T.P.S.
A
E
C
K
C
E
K
A



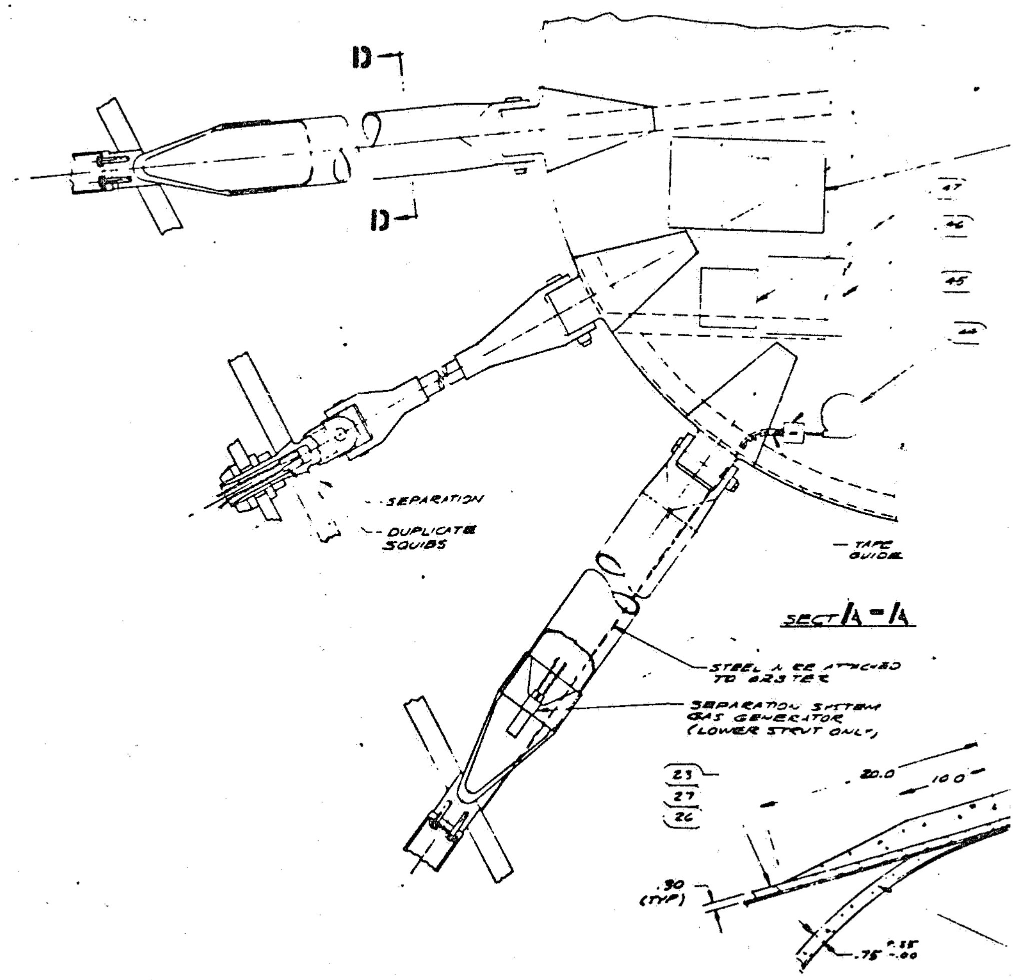
SECT. C - C
TYP FOR VENT AND PRESSURE LINES



SECT D - D
TYP ALL TANK SUPPORTS



SECT E - E
TYP FOR CONE



SECT A - A

VIEW F
SHOWING T.P.S. ON TAN
DOME AND NOSE CON

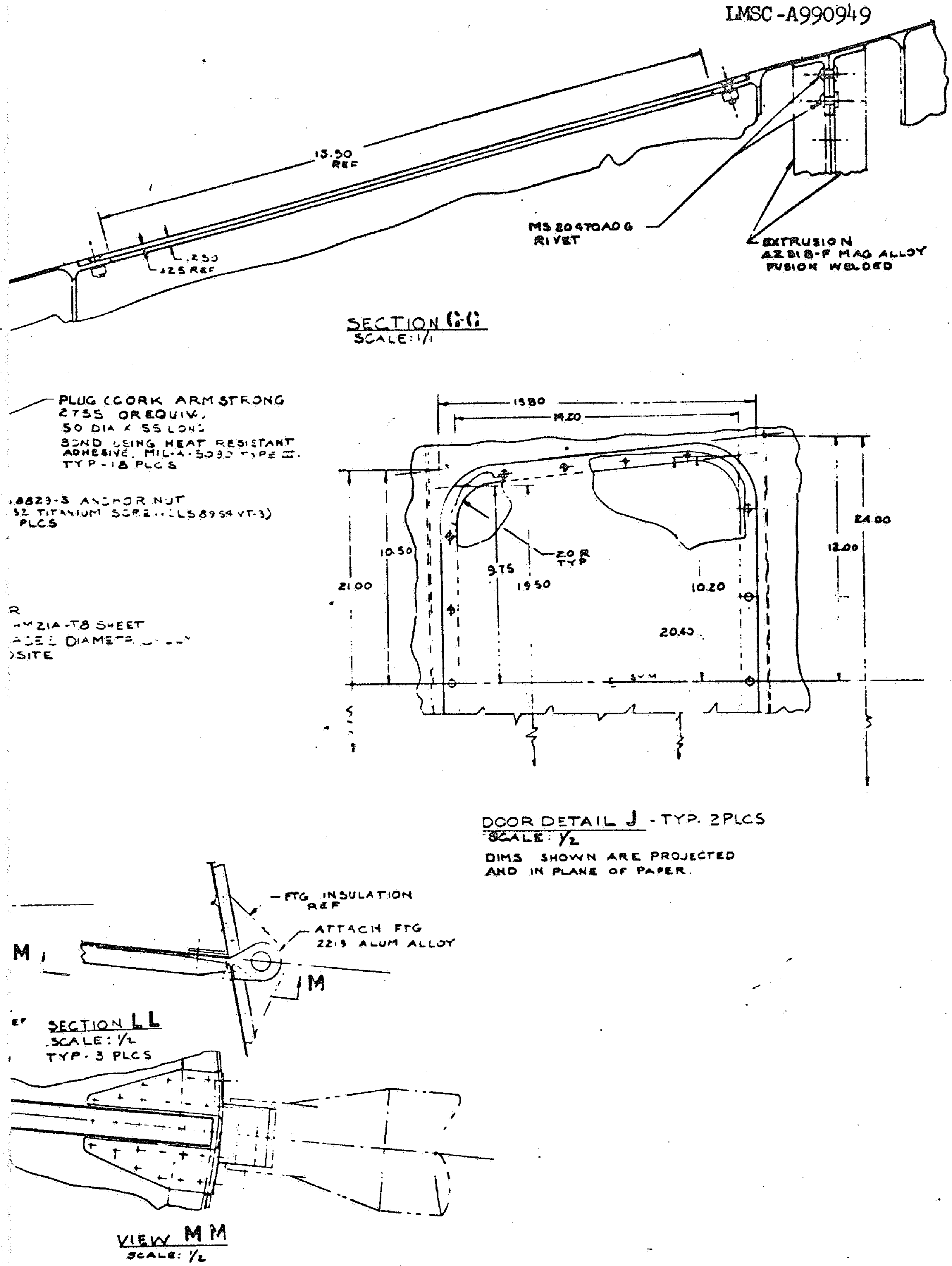
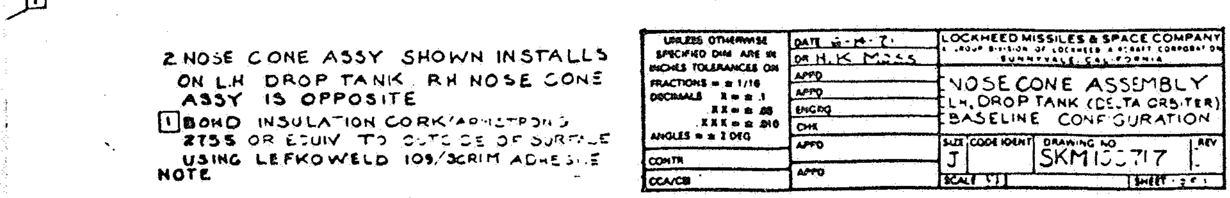
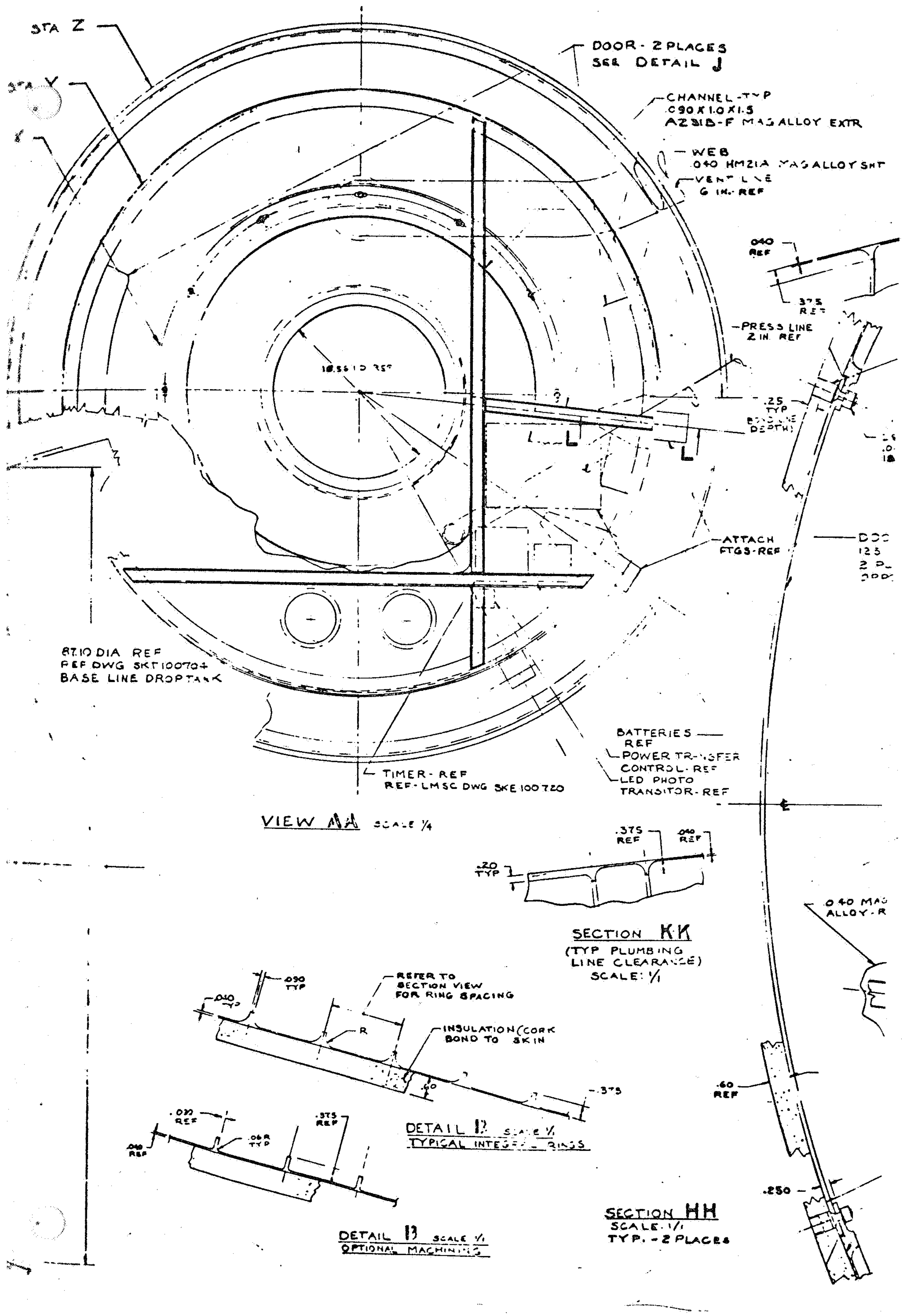
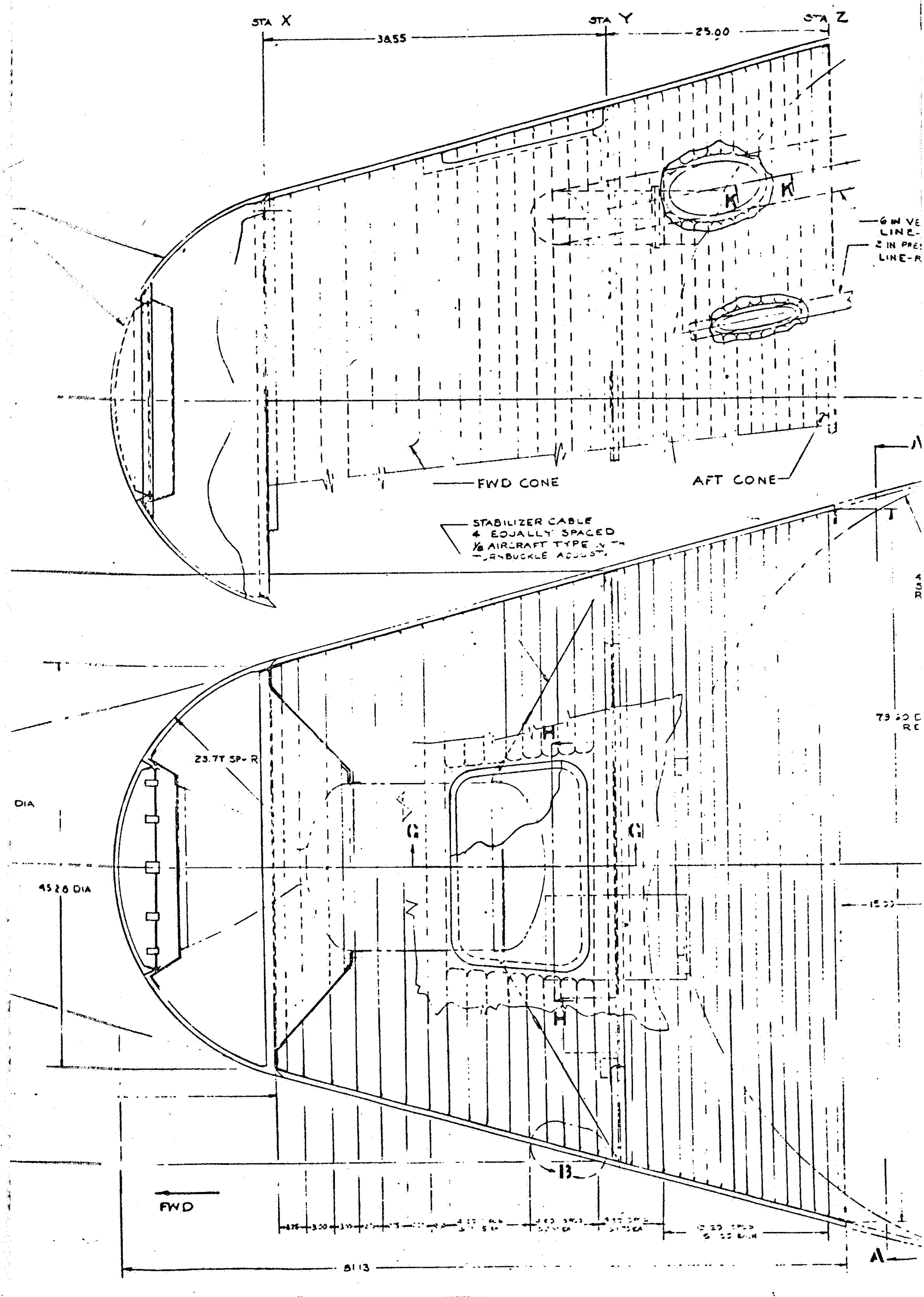


Fig. 9-3 Nose Cone Assembly

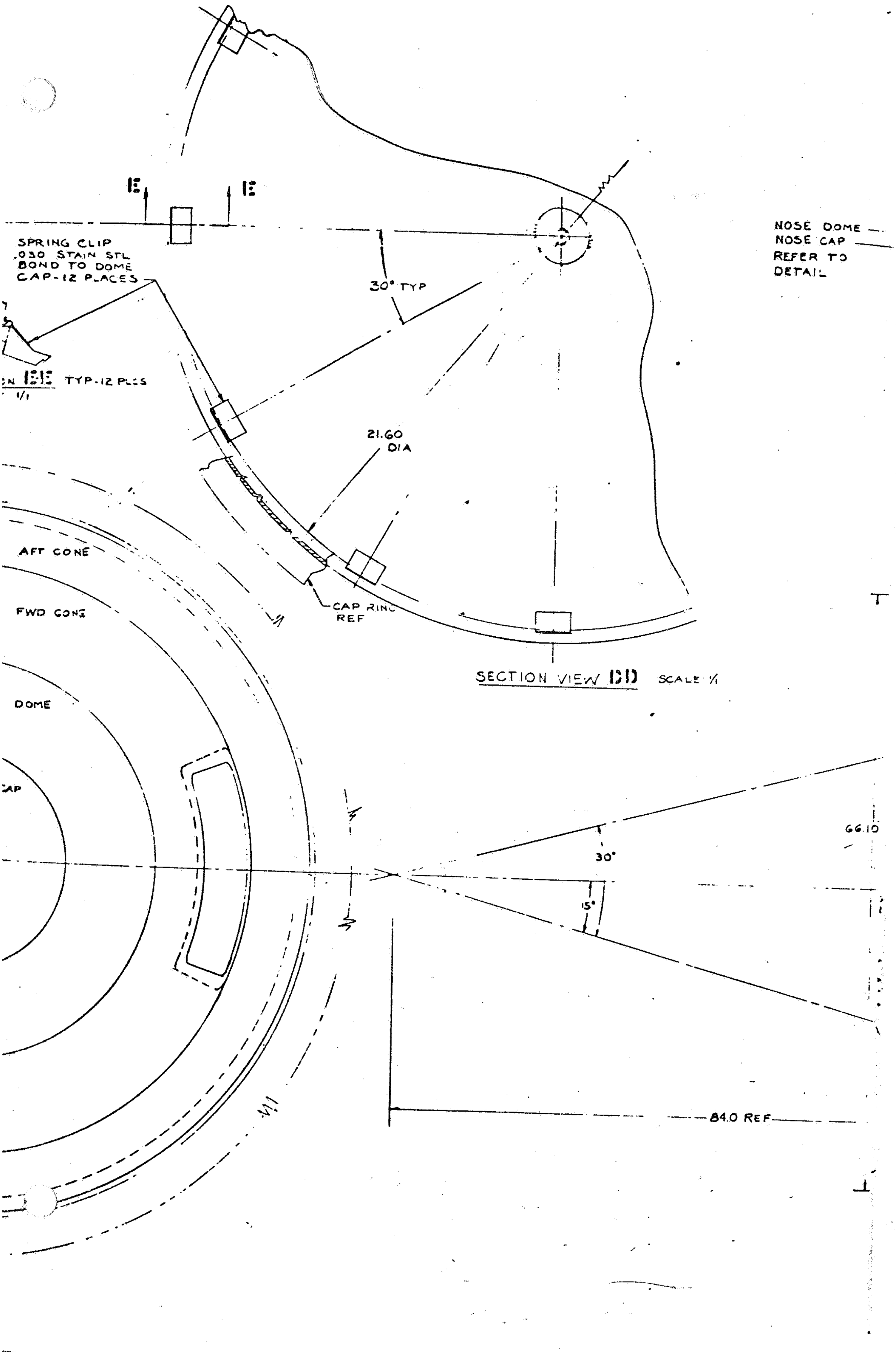




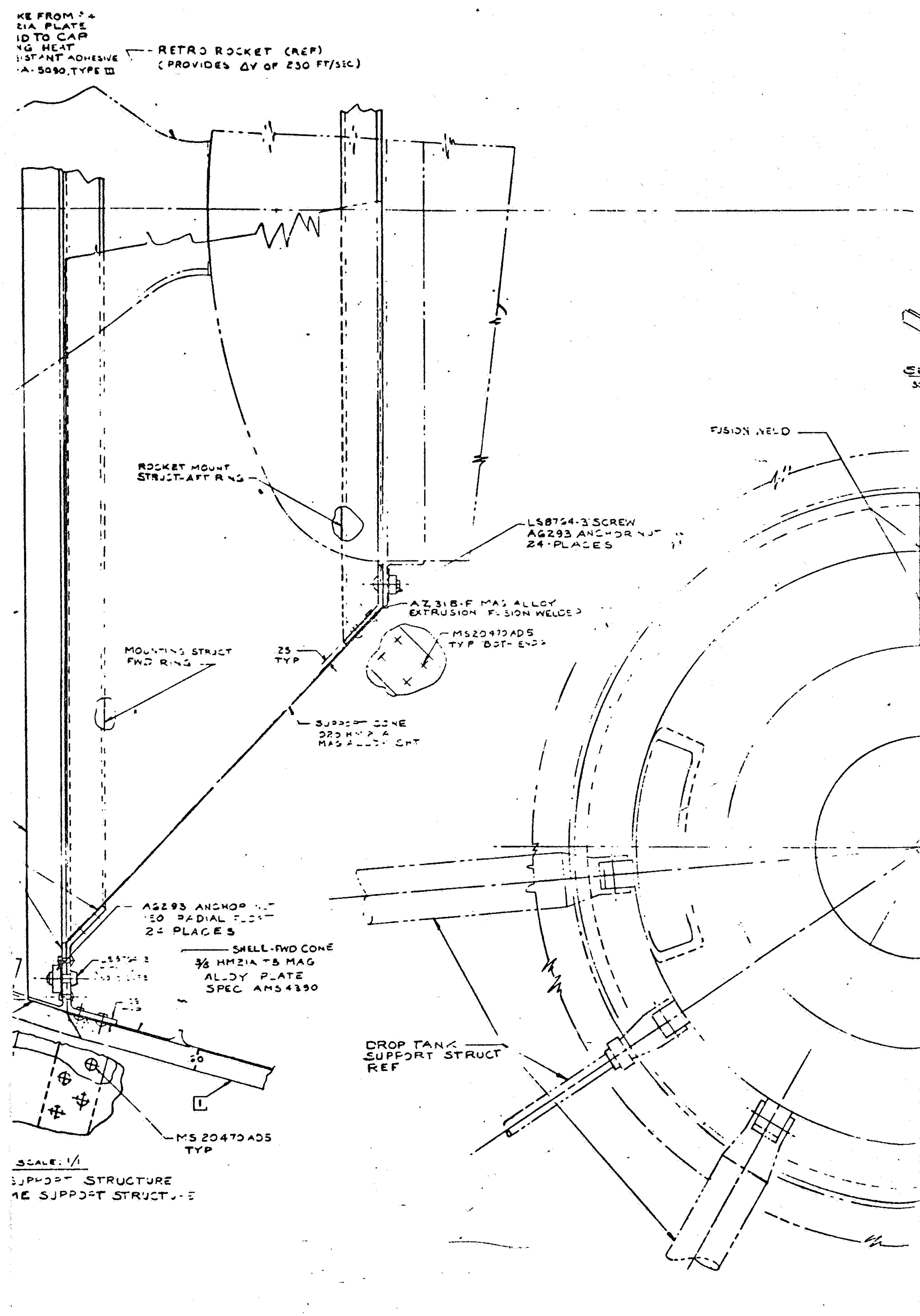
STA Z
STA Y
DOOR - 2 PLACES
SEE DETAIL J
CHANNEL - TYP
.090 X 1.0 X 1.5
AZ31B-F MAG ALLOY EXTR
WEB
.040 HM21A MAG ALLOY SHT
VENT LINE
6 IN. REF
.040
REF
.375
REF
PRESS LINE
2 IN. REF
.25
TYP
DEPTH)
ATTACH
FTGS - REF
87.10 DIA REF
REF DWG SKT100704
BASE LINE DROPTANK
BATTERIES
REF
POWER TRANSFER
CONTROL - REF
LED PHOTO
TRANSITOR - REF
TIMER - REF
REF - LMSC DWG SKE 100720
VIEW AA SCALE 1/4
.375
REF
.040
REF
.20
TYP
SECTION KK
(TYP PLUMBING
LINE CLEARANCE)
SCALE: 1/1
.040 MAG
ALLOY - R
.090
TYP
.040
TYP
REFER TO
SECTION VIEW
FOR RING SPACING
R
INSULATION (CORK
BOND TO SKIN
.60
.375
DETAIL B SCALE 1/1
TYPICAL INTEGRAL RINGS
.60
REF
.090
REF
.375
REF
.06 R
TYP
.040
REF
.250
SECTION HH
SCALE 1/1
TYP. - 2 PLACES
DETAIL B SCALE 1/1
OPTIONAL MACHINING



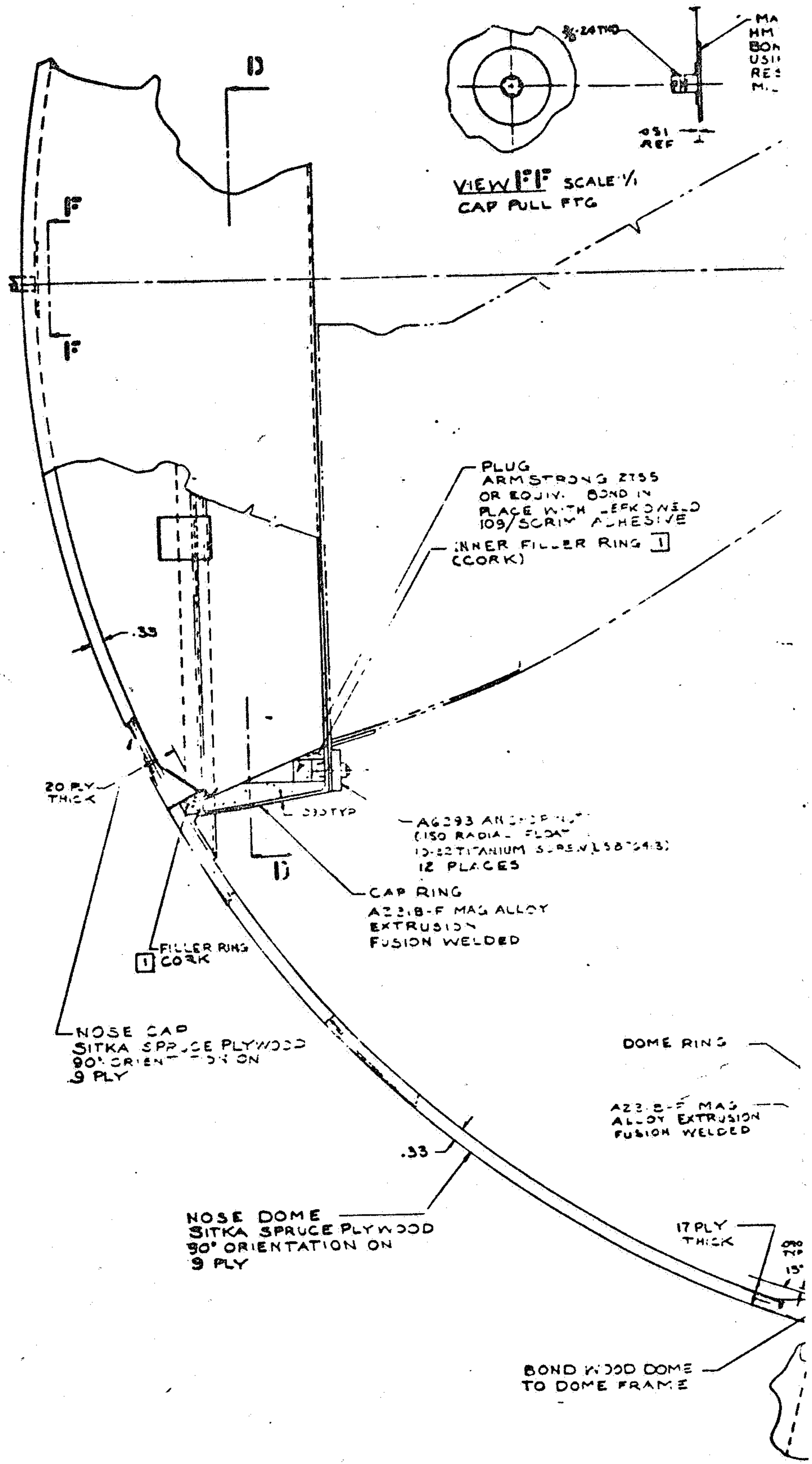
STA X
STA Y
STA Z
38.55
25.00
FWD CONE
AFT CONE
STABILIZER CABLE
4 EQUALLY SPACED
1/8 AIRCRAFT TYPE
23.77 SP. R
DIA
45.28 DIA
FWD
81.13
K
G
H
B
A



E
E
SPRING CLIP
.030 STAIN STL
BOND TO DOME
CAP-12 PLACES
30° TYP
TYP-12 PLCS
21.60
DIA
CAP RING
REF
NOSE DOME
NOSE CAP
REFER TO
DETAIL
SECTION VIEW DD
SCALE 1/1
AFT CONE
FWD CONE
DOME
30°
15°
66.10
84.0 REF



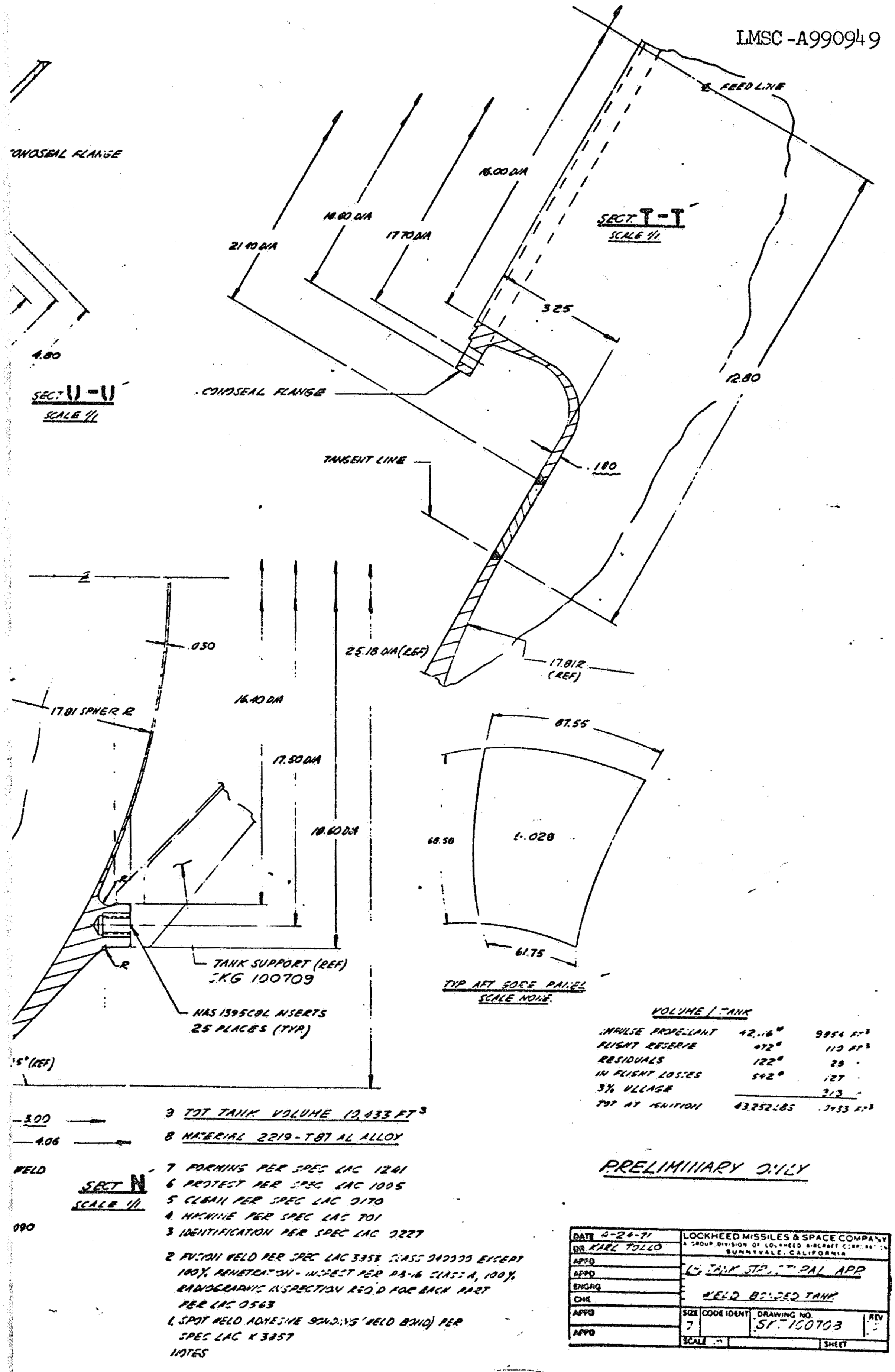
KE FROM
IA PLATE
ID TO CAP
G HEAT
ISTANT ADHESIVE
A-5090, TYPE III
RETRO ROCKET (REF)
(PROVIDES ΔV OF 230 FT/SEC)
ROCKET MOUNT
STRUCT-AFT RING
LS8764-3 SCREW
AG293 ANCHOR NUT
24 PLACES
AZ31B-F MAG ALLOY
EXTRUSION FUSION WELDED
MS20470AD5
TYP BOTH ENDS
MOUNTING STRUCT
FWD RING
.25
TYP
SUPPORT CONE
FUSION WELD
AG293 ANCHOR NUT
24 PLACES
SHELL-FWD CONE
3/8 HM21A T8 MAG
ALLOY PLATE
SPEC AMS4390
DROP TANK
SUPPORT STRUCT
REF
MS20470AD5
TYP
SCALE: 1/1
SUPPORT STRUCTURE
ME SUPPORT STRUCTURE



DETAIL C

(1) ROCKET

(2) NOSE DOM



9-4 LH$_2$ Tank Structural Arrangement, Weld Bonded Tank

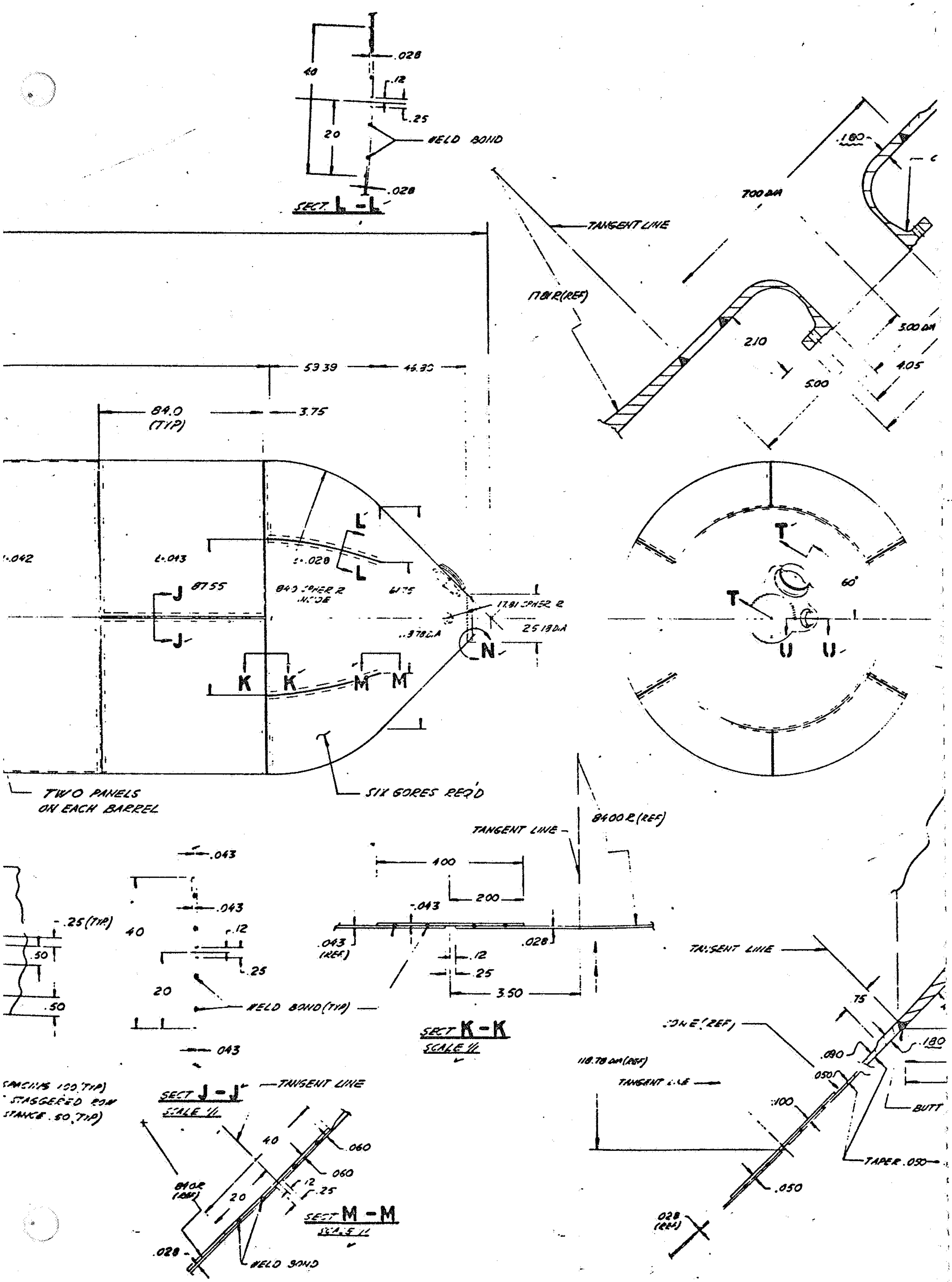
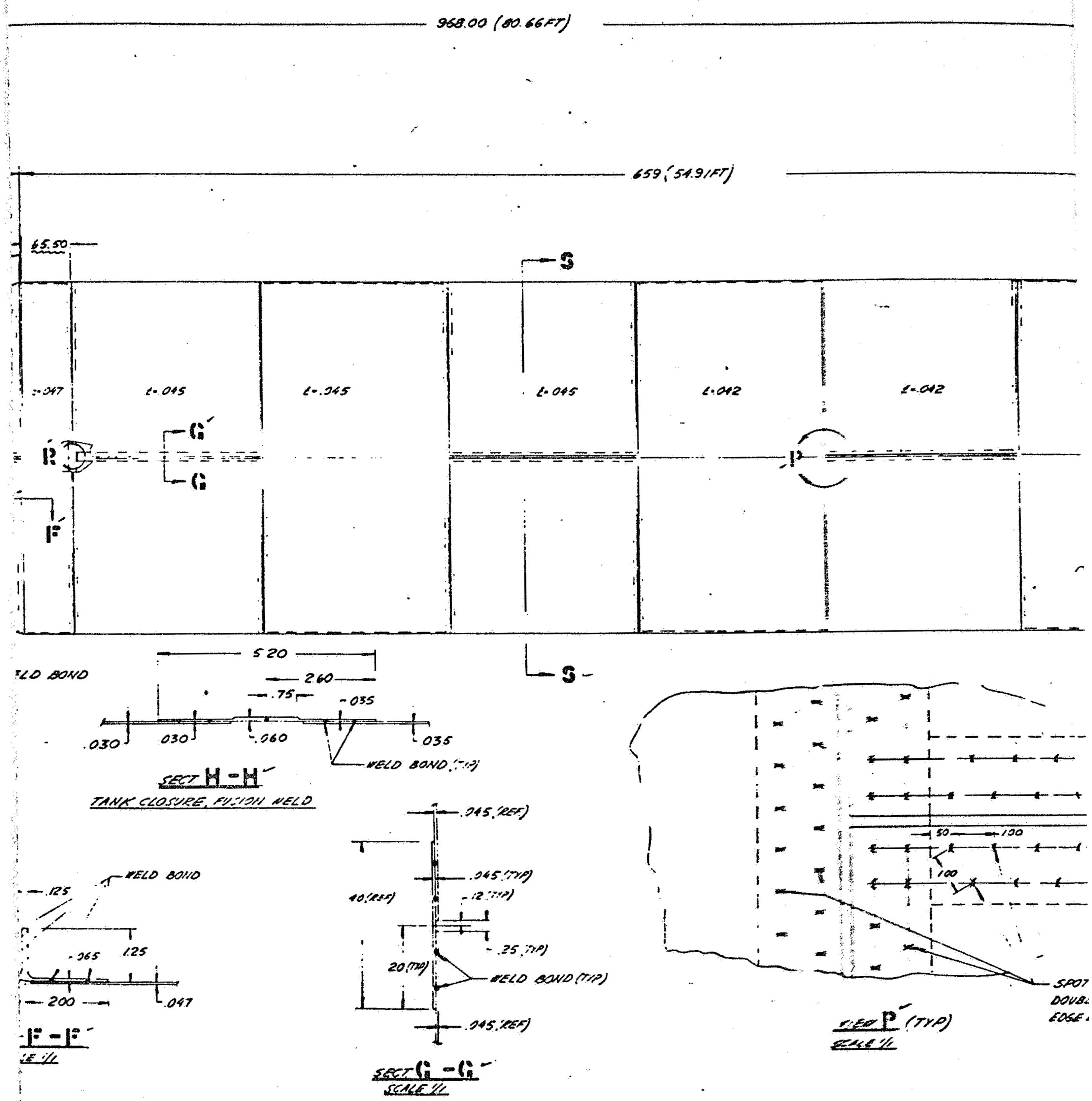
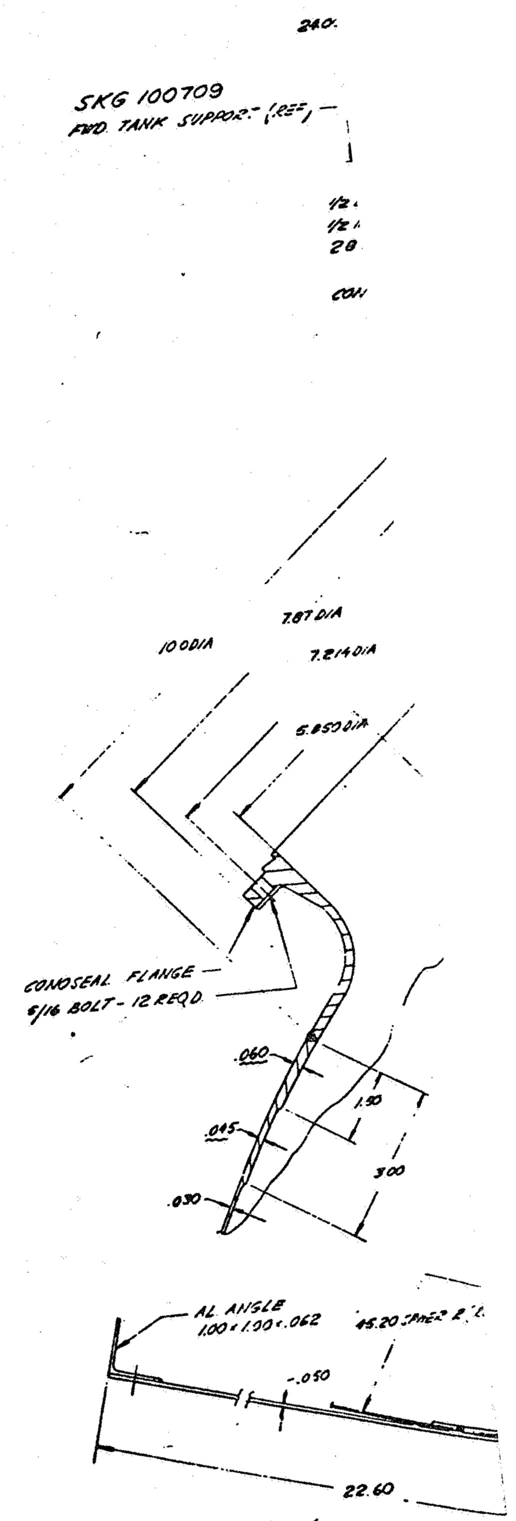

SECT L-L
WELD BOND
TANGENT LINE
17.81 R (REF)
7.00 DIA
3.00 DIA
2.10
5.00
4.05
.180
53.39
46.30
84.0 (TYP)
3.75
87.55
84.0 SPHER R INSIDE
17.81 SPHER R
2.518 DIA
SIX GORES REQ'D
TWO PANELS ON EACH BARREL
60°
TANGENT LINE
84.00 R (REF)
.25 (TYP)
WELD BOND (TYP)
SECT J-J
SCALE 1/1
SECT K-K
SCALE 1/1
3.50
.043 (REF)
TANGENT LINE
CONE (REF)
118.78 DIA (REF)
TAPER .050
BUTT
SECT M-M
SCALE 1/1
84.0 R (REF)
WELD BOND
.028 (REF)

Fig.



968.00 (80.66FT)
659 (54.91FT)
65.50
S
G
G
R
F
P
520
2.60
.75
.035
.030
.030
.060
.035
WELD BOND (TYP)
SECT H-H
TANK CLOSURE, FUSION WELD
WELD BOND
.125
.065
.125
200
.047
F-F
.045 (REF)
.045 (TYP)
.12 (TYP)
40 (REF)
.25 (TYP)
20 (TYP)
WELD BOND (TYP)
.045 (REF)
SECT G-G
SCALE 1/1
50
100
100
VIEW P (TYP)
SCALE 1/1



VIEW D
SCALE 1/1

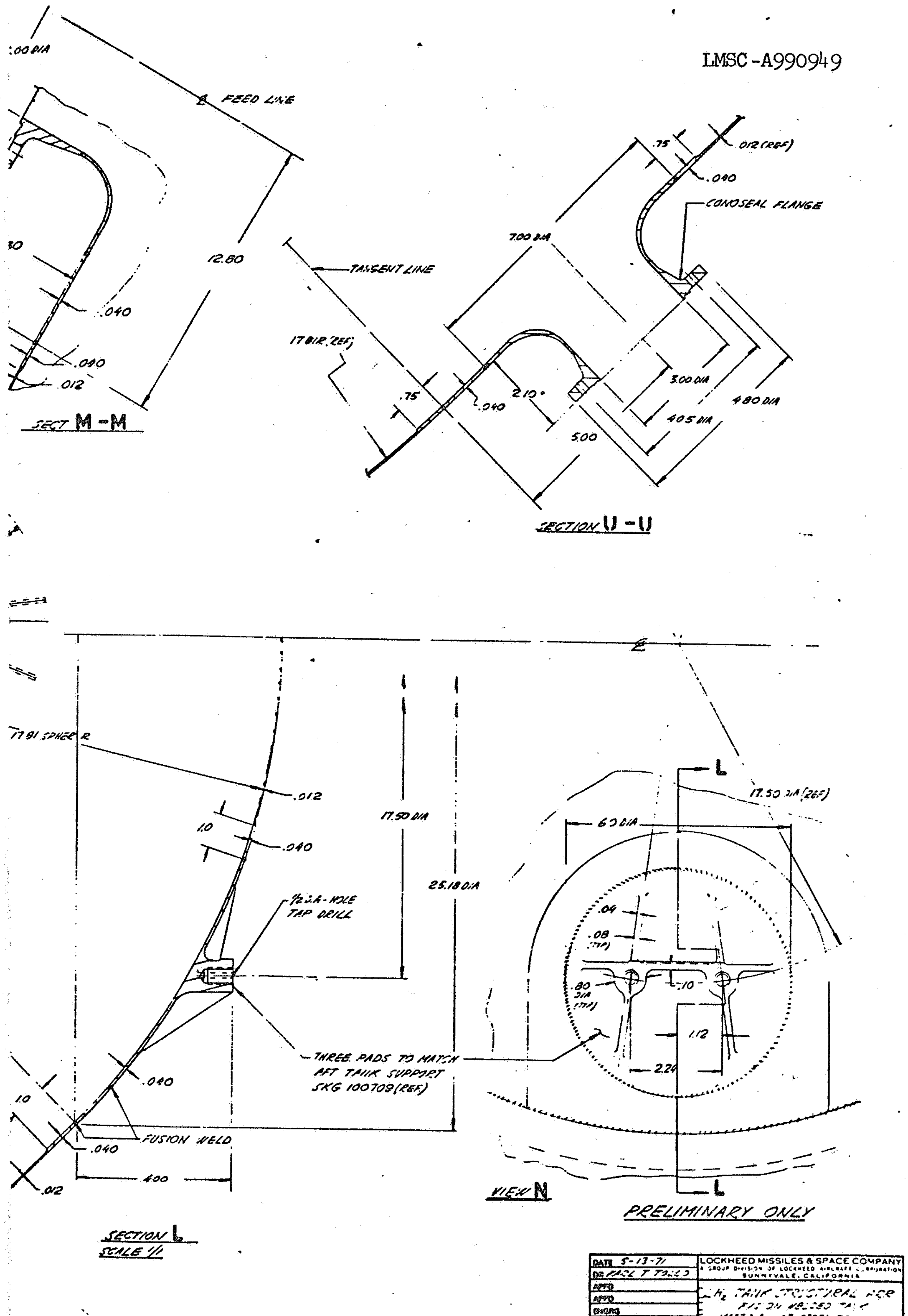
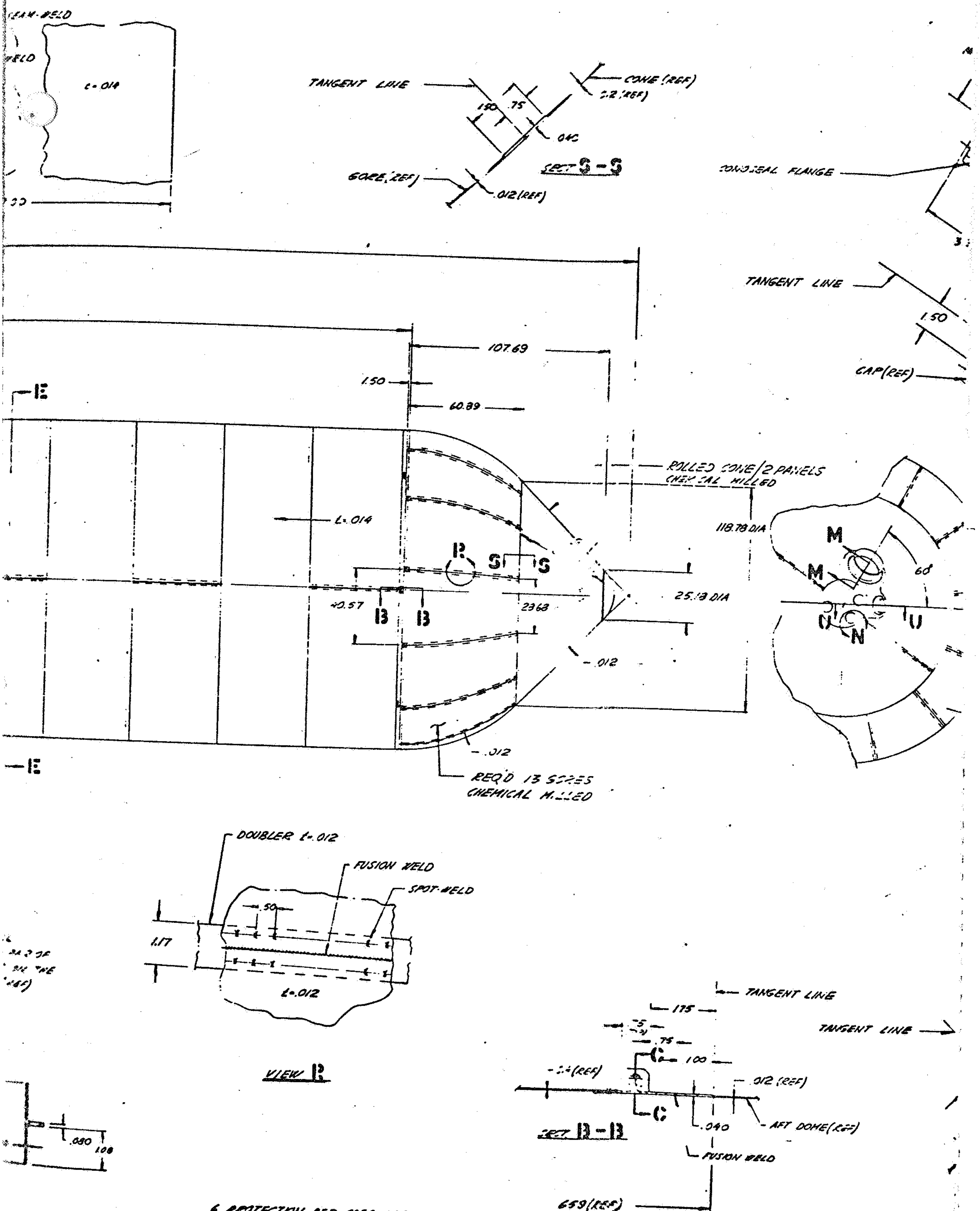
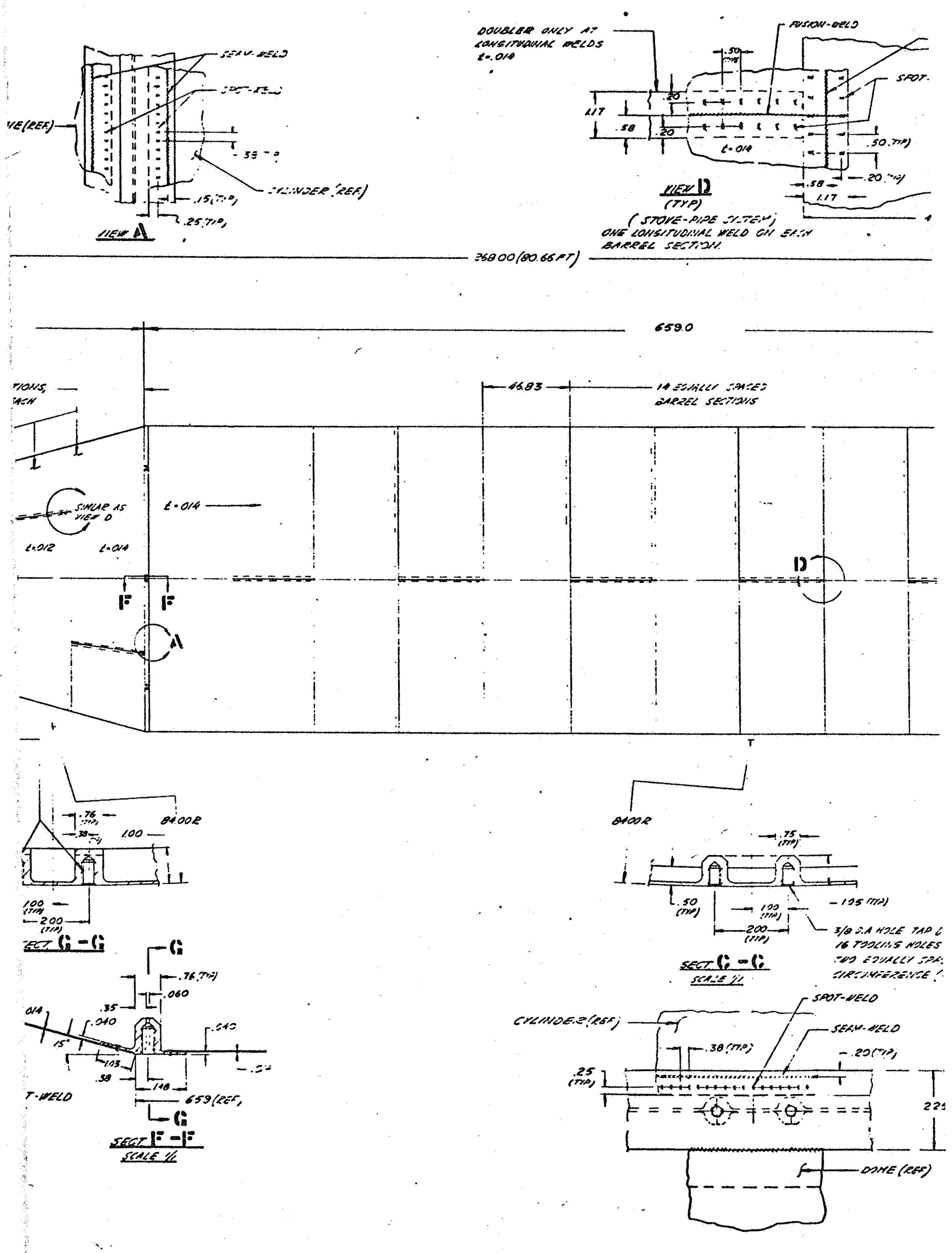


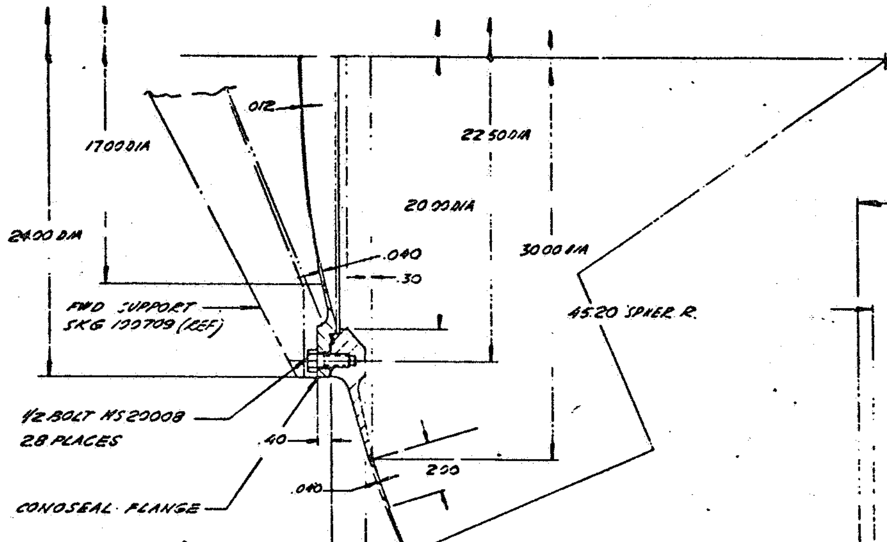
Fig. 9-5 Fusion Welded Tank



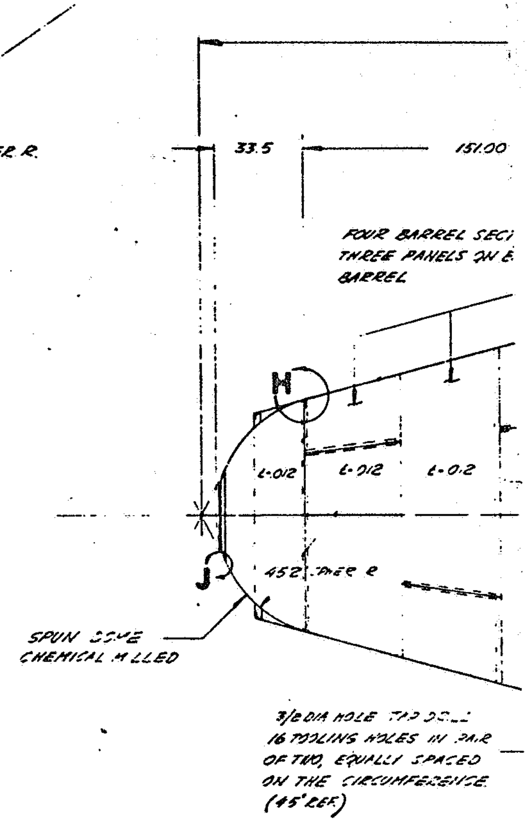
6 PROTECTION PER SPEC LAC 1005
5 CLEAN PER SPEC LAC 0170
4 MACHINE PER SPEC LAC 701
3 FORMING PER SPEC LAC 1241
2 TOT TANK VOLUME 10.433 FT³
1. MATERIAL 301 STAINLESS STEEL (EXTRA HARD)
NOTES:

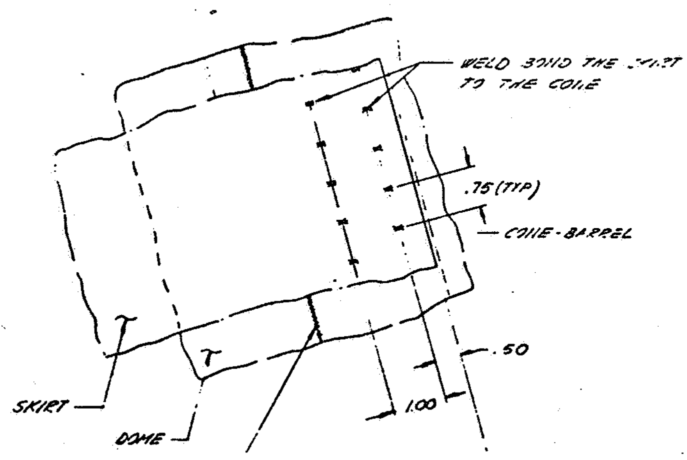


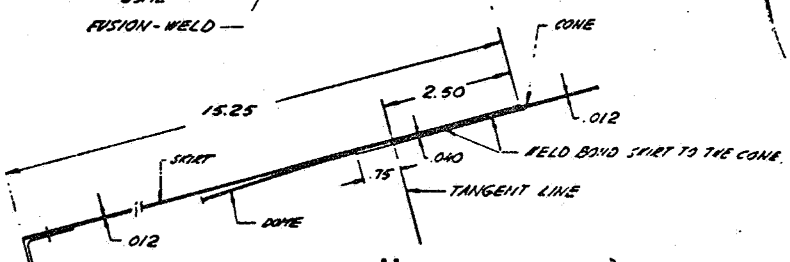
VIEW A
SEAM-WELD
CYLINDER (REF)
.15 (TYP)
.25 TYP
DOUBLER ONLY AT LONGITUDINAL WELDS t=.014
FUSION-WELD
SPOT-
VIEW D
(TYP)
(STOVE-PIPE SYSTEM)
ONE LONGITUDINAL WELD ON EACH BARREL SECTION
.50 TYP
.20 TYP
1.17
.58
t=.014
268.00 (80.66 FT)
659.0
46.83
14 EQUALLY SPACED BARREL SECTIONS
t=.014
SIMILAR AS VIEW D
t=.012
84.00 R
1.00
SECT G-G
SECT F-F
SCALE 1/1
.76 TYP
.060
.35
.040
15°
.103
.38
.148
659 (REF)
T-WELD
8400 R
.75 (TYP)
.50 (TYP)
1.00 (TYP)
2.00 (TYP)
.195 (TYP)
3/8 DIA HOLE TAP
16 TOOLING HOLES
TWO EQUALLY SPACED
CIRCUMFERENCE
SECT C-C
SCALE 1/1
SPOT-WELD
SEAM-WELD
CYLINDER (REF)
.38 (TYP)
.20 (TYP)
.25 (TYP)
DOME (REF)



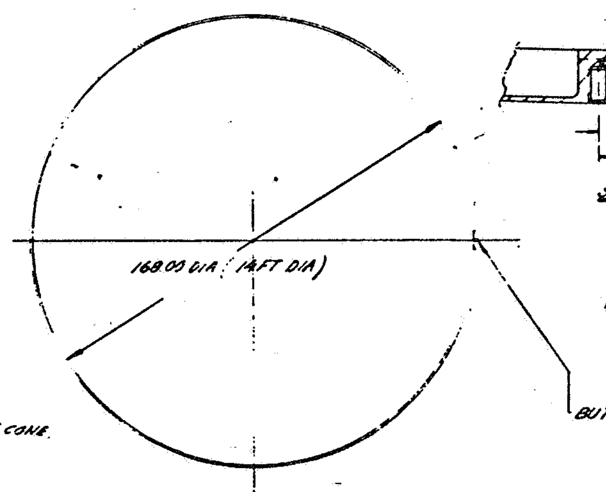
VIEW J
SCALE 1/2







VIEW H
SCALE 1/1



SECT E-E
SCALE 1/20

9.4 WEIGHTS

The following section delineates the weights and the logic followed in their derivation for three basic tank configuration concepts. The three configurations designated A, B, and C are:

Configuration A — Fusion-welded 2219-T81 Al.

Configuration B — Weld-bonded 2219-T87 Al.

Configuration C — Fusion-spotwelded Type 301 stainless steel

The information in Tables 9-1 and 9-2 deals specifically with Configuration A, established as the baseline system. Table 9-1 is the detailed weight breakdown for a complete set of tanks (Config. A). Table 9-2 is a mass properties summary for Configuration A. Table 9-3 is a structural weight comparison of the three configurations for detailed costing purposes.

The weights were developed in the following manner. For the tank structure, detailed in Table 9-2, the nominal gages determined by structural considerations of external and internal loadings and temperature were used to size the basic membrane. To these were added the basic sheet standard tolerances and the forming and chemical milling tolerances where applicable. Configuration B, however, utilized only one-half of the standard sheet tolerances and thereby showed a weight savings (but accepted a material cost penalty for the smaller acceptable mill tolerance).

Detailed calculations were then performed for penetrations, weld lands and doublers, bonding agents, and all discontinuity areas where rings were required. The final assembly weights were then compared to the basic membrane to determine, as a matter of interest, what the associated nonoptimum factor (NOF) might be. It was found that the NOF was in the order of 35 percent. This NOF was then applied for conservatism to the weights calculated for the skirts fore and aft and also for the nose fairing structure and tank-to-spacecraft attachments. An estimate of 15 percent of the group weight was employed for bracketry and supports in the equipment and feedline groups. The NOF for the thermal protection system was estimated as 5 percent based upon a sprayed on foam insulation (SOFI) tolerance of +.25 -.00 and a cork tolerance of +.025 -.00.

The separation and deorbit systems, which along with the bracketry and support items mentioned above and the contingency allotment, are the only weights not derived as a result of detailed design analysis, are based upon the use of solid propellant charges or rockets and were derived on assumed data as follows:

Retrorocket Design

- 1g deceleration
- ISP = 250 sec
- ΔV = 200 ft/sec
- λ' = 0.80 (Motor)

The tank-from-spacecraft separation charges were estimated on the basis of a one-half gravity acceleration for a period of 1 sec.

The overall tank contingency allotment is 10 percent and is quite conservative when considering the detailed calculations involved, but is deliberately maintained in consideration of dynamic unknowns, such as baffles, anti-vortex and positioning screens, and possible fluid flow structural interactions (pogo) that might be detected later as more information becomes available.

LOCKHEED

EXTERNAL TANK WEIGHTS
CONFIGURATION A - FUSION-WELD 2219-T81 ALUMINUM

ITEM	WEIGHT (LB)*
STRUCTURE	(6,202)
NOSE FAIRING	204
FORWARD DOME	764
CYLINDER	3,886
AFT DOME	460
AFT SKIRT	61
FORWARD ATTACH	157
AFT ATTACH	670
INSULATION (ASCENT/ENTRY PROTECT)	(7,354)
NOSE	120
FORWARD DOME SECTION	1,284
CYLINDER	4,922
AFT DOME SECTION	604
LINES	424
SEPARATION	(170)
DEORBIT SYSTEM	(680)
PROPULSION	(1,388)
FEED, PRESS, EVENT	1,106
INST. POWER	282
CONTINGENCY (10 PERCENT)	(1,578)
DRY WEIGHT	(17,372)
RESIDUALS	304
RESERVES	2,028
INERT TOTAL	(19,704)

*WEIGHTS FOR TWO TANKS

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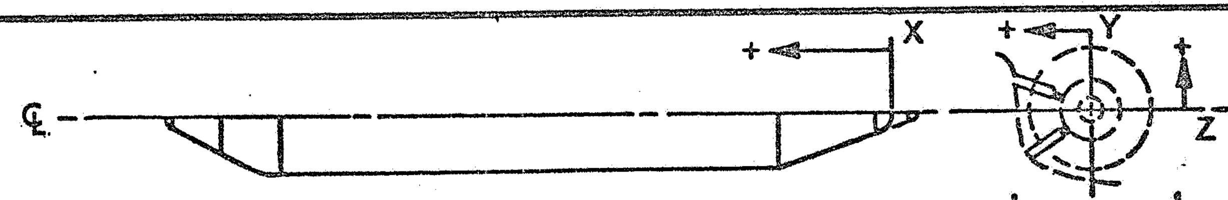
Table 9-1

MASS PROPERTIES - CONFIGURATION A



ITEM OR CONDITION	WEIGHT (LB)	X (IN.)	Y (IN.)	Z (IN.)	I_X (SLUG-FT^2)	I_Y (SLUG-FT^2)	I_Z (SLUG-FT^2)
STRUCTURE	(3101.0)						
NOSE FAIRING	102.0	-5.7	0	0	18	20	20
FWD DOME SECTION	382.0	101.6	0	0	304	268	268
CYLINDER	1943.0	512.1	0	0	2,957	16,643	16,643
AFT DOME	230.0	911.1	0	0	122	80	80
AFT SKIRT	30.5	859.0	0	0	46	23	23
FWD ATTACHMENTS	78.5	-1.0	+60	-25	84	50	35
AFT ATTACHMENTS	335.0	965.2	±40	-15	363	215	185
INSULATION	(3677.0)						
NOSE FAIRING	60.0	-5.7	0	0	10	13	13
FWD DOME SECTION	642.0	101.6	0	0	480	423	423
CYLINDER AND SKIRT	2461.0	517.5	0	0	3,580	19,850	19,850
AFT DOME SECTION	302.0	911.1	0	0	185	120	120
LINES	212.0	837.0	±60	-90	250	150	150
SEPARATION SYSTEM	(85.0)	963.0	0	0	5	3	3
DEORBIT SYSTEM	(340.0)	198.2	0	0	-	25	25
PROPULSION SYSTEM	(694.0)						
FEED, VENT AND DRAIN	553.0	837.0	+60	-90	600	355	355
INSTRUMENT. AND POWER	141.0	837.0	±60	-90	153	92	92

Table 9-2

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Table 9-2

LOCKHEED

MASS PROPERTIES - CONFIGURATION A (Cont'd)

ITEM OR CONDITION	WEIGHT (LB)	X (IN.)	Y (IN.)	Z (IN.)	I_X (SLUG-FT^2)	I_Y (SLUG-FT^2)	I_Z (SLUG-FT^2)
CONTINGENCY	(789.0)	520.9	+9.2	-11.2	915	3,833	3,828
TANK DRY WEIGHT	(8686.0)	(520.9)	(±9.2)	(-11.2)	(12,219)	(167,185)	(166,474)
RESIDUALS	152.0	850.0	0	0	165	98	98
RESERVES	472.0	907.0	0	0	0	5,800	5,800
TANK INERT WEIGHT	(9310.0)	(545.8)	(±8.6)	(-10.5)	(12,409)	(189,586)	(188,870)
IN-FLIGHT LOSSES	542.0	907.0	0	0	0	6,150	6,150
IMPULSE	42116.0	521.5	0	0	0	550,000	550,000
TANK LOADED WEIGHT LESS:	(51968.0)	(529.9)	(±1.5)	(-1.9)	(12,699)	(764,520)	(763,750)
IMPULSE	-42116.0	521.5	0	0	0	-550,000	-550,000
IN-FLIGHT LOSSES	-542.0	907.0	0	0	0	-6,150	-6,150
L[1] S.O.F.I. AND COATING	-668.0	487.1	+3.5	-5.2	-848	-3,870	-3,870
TANK INJECTION LESS:	(8642.0)	(550.4)	(∓9.0)	(-10.9)	(11,553)	(184,985)	(184,270)
L[2] NOSE FAIRING	-102.0	-5.7	0	0	-18	-20	-20
L[2] NOSE INSULATION	-26.0	-5.7	0	0	-5	-7	-7
L[2] RETRO ROCKET	-275.0	-17.0	0	0	0	-25	-25
SPIN-UP PROPELL.	-5.0	860.0	0	0	0	0	0
TUMBLING PROPELL.	-25.0	860.0	0	0	0	0	0
SEPARATION SYS.	-78.0	963.0	±60	-50	-4	-2	-2
PURGED RESERVES	-472.0	907.0	0	0	0	-5,800	-5,800
L[3] FWD ATTACH	-69.0	-1.0	+60	-25	-74	-44	-31
L[3] AFT ATTACH	-310.0	965.2	∓40	-15	-336	-199	-171
PYRO DISCONNECT AND CLMP.	-26.0	837.0	±60	-90	0	0	0
TANK AT INITIAL ENTRY	(7254.0)	(539.2)	(±7.5)	(-11.2)	(10,800)	(118,696)	(118,311)

L[1] — IT IS ASSUMED THAT THE POLYURETHANE FOAM IS ERODED DURING ASCENT BY VISCOUS SHEARING ACTION FROM THE FLOW

L[2] — THE NOSE FAIRING IN COMBINATION WITH THE RETRO ROCKET IS JETTISONED PRIOR TO REENTRY

L[3] — APPROXIMATELY 34 LB OF ATTACHMENTS REMAIN WITH TANK AFTER SEPARATION

103347

Table 9-2 (Cont'd)

Table 9-2 (Cont'd)

LOCKHEED

TANK STRUCTURAL WEIGHT COMPARISON

ITEM OR CONDITION	CONFIG. A FUSION WELD 2219-T81 AL.	CONFIG. B WELD BOND 2219-T87 AL.	CONFIG. C FUSION-SPOT WELD TYPE 301 SS
FORWARD CAP	(66.6)	(66.6)	(84.6)
MEMBRANE	63.7	63.7	81.1
SHEET TOL.	1.9	1.9	2.5
MFG TOL.	1.0	1.0	1.0
CHEM MILL TOL.	-	-	-
FORWARD SKIRT	(31.0)	(31.0)	(41.3)
MEMBRANE	28.2	28.2	37.5
SHEET TOL.	1.1	1.1	1.5
MFG TOL.	-	-	-
CHEM MILL TOL.	1.7	1.7	2.3
FORWARD CONE	(284.5)	(306.4)	(392.1)
MEMBRANE	253.4	250.0	346.8
SHEET TOL.	12.4	6.2	16.5
MFG TOL.	-	-	-
CHEM MILL TOL.	18.7	-	-
DOUBLERS	-	48.8	28.8
BOND	-	1.4	-
TRANSITION RING	(23.7)	(23.7)	(28.4)
CYLINDER	(1919.5)	(1779.6)	(1605.3)
MEMBRANE	1462.5	1455.1	1194.0
SHEET TOL.	351.5	175.8	283.2
MFG TOL.	-	-	-
CHEM MILL TOL.	105.5	-	-
DOUBLERS	-	144.0	128.1
BOND	-	4.7	-

Table 9-3

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Table 9-3

TANK STRUCTURAL WEIGHT COMPARISON (Cont'd)

ITEM OR CONDITION	CONFIG. A FUSION WELD 2219-T81 AL.	CONFIG. B WELD BOND 2219-T87 AL	CONFIG. C FUSION-SPOT WELD TYPE 301 SS
AFT SPHERICAL SEG	(111.5)	(115.0)	(156.2)
MEMBRANE	94.5	94.0	125.6
SHEET TOL.	6.8	3.4	9.0
MFG TOL.	-	-	-
CHEM MILL TOL.	10.2	-	-
DOUBLERS	-	15.6	21.6
BOND	-	2.0	-
AFT CONE AND CAP	(118.0)	(117.2)	(84.4)
MEMBRANE	103.7	103.2	76.2
SHEET TOL.	3.0	3.0	2.0
MFG TOL.	7.8	7.6	4.0
CHEM MILL TOL.	3.5	3.4	2.2
DOUBLERS	-	-	-
BOND	-	-	-
SUMMATION (ONE TANK)	2554.5	2439.5	2392.3

Table 9-3 (Cont'd)

Table 9-3 (Cont'd)

Section 10
STRUCTURES

The two-and-one-half stage structural system employs a space-shuttle orbiter in combination with two nonrecoverable LH_2 propellant tanks, simply supported on the orbiter (GAC DWG B3L0193-1056). Each droptank assembly is attached to the orbiter at two locations: one forward in the nose section, reacting only transverse loads, and one aft at the orbiter aft payload compartment bulkhead, reacting omnidirectional loads.

In support of the study requirements to evaluate the weight and program costs for this concept, preliminary structural analyses of the GAC configuration were performed. After careful screening of candidate materials, the study narrowed to two: 2219 aluminum and 301 stainless steel - extra hard temper. Two design load environments were evaluated: ascent loading and intact entry. Included here are the summaries and results of the various structural considerations and parametric studies performed. The detailed analyses are presented in Engineering Memorandums included in the appendix of this report. The data are representative of the GAC and NAR configurations.

10.1 LOADS ANALYSIS

10.1.1 Ascent Loads

Two ascent conditions have been investigated for critical droptank loads. The first condition occurs at max $\pm \alpha q$ where the normal load factor is assumed to be $\pm$ 0.4g. An αq value of 2000 deg psf has been established from previous space shuttle analysis. Aerodynamic loading has been estimated from wind tunnel tests which shows interference effects of bodies in close proximity to each other. A better definition of aerodynamic loading on the tanks will require wind tunnel testing of the particular configuration.

Preliminary estimates of tank bending moment are shown in Fig. 10-1A. Revised estimates of tank bending moment, based on recent preliminary wind tunnel data, are shown in Fig. 10-1B. Axial loads at max α q are shown in Fig. 10-2. The axial loads are based on a drag coefficient of 0.02 and an axial load factor, n_x, of 1.7 which includes 0.3 g dynamic effect.

Droptank attachment loads at max $\pm\alpha$q are shown on Fig. 10-3A. The inertia loads and estimated aerodynamic loads are considered separately and/or combined to give maximum values for the design of the droptank reactions, because the airloads are not well defined. Revised attachment loads at max $\pm \alpha$ q, and max $\pm \beta$ q, based on the recent preliminary wind tunnel data, are shown in Figure 10-3B. Time did not permit this data to be completely incorporated in the Structural Analysis.

The second condition investigated is maximum axial acceleration where the axial acceleration is 3g, including dynamic effects. The aft tank reaction is shown in Fig. 10.3. A distribution of axial load for this condition is shown in Fig. 10-2. The details of this analysis are presented in EM L2-12-01-M1-12 (see Appendix).

10.1.2 Reentry Loads

Tank reentry loads were calculated for two conditions. Before detailed 6-degree-of-freedom reentry studies were completed, the tank was assumed to be tumbling so that α = 90 deg could occur at any point on the trajectory. These moments and tension loads, in unit form, are shown in Fig. 10-4. Estimated dynamic pressure $(\bar{q})$ of 100 psf and rotational velocity (ω) of 0.6 rad/sec were used in the load calculation.

The 6-degree-of-freedom studies show the tank to be stable, and reentering nose first, for all conditions investigated. Rotational velocities of approximately 0.1 rad/sec were obtained so that the tension caused is negligible. Total angles-of-attack of the order of 40 deg resulted.

Unit moment and axial load for these conditions are shown in Fig. 10-5. A dynamic pressure of 630 psf results for the most severe condition.

DROPTANK BENDING MOMENT

MAX. αq CONDITION

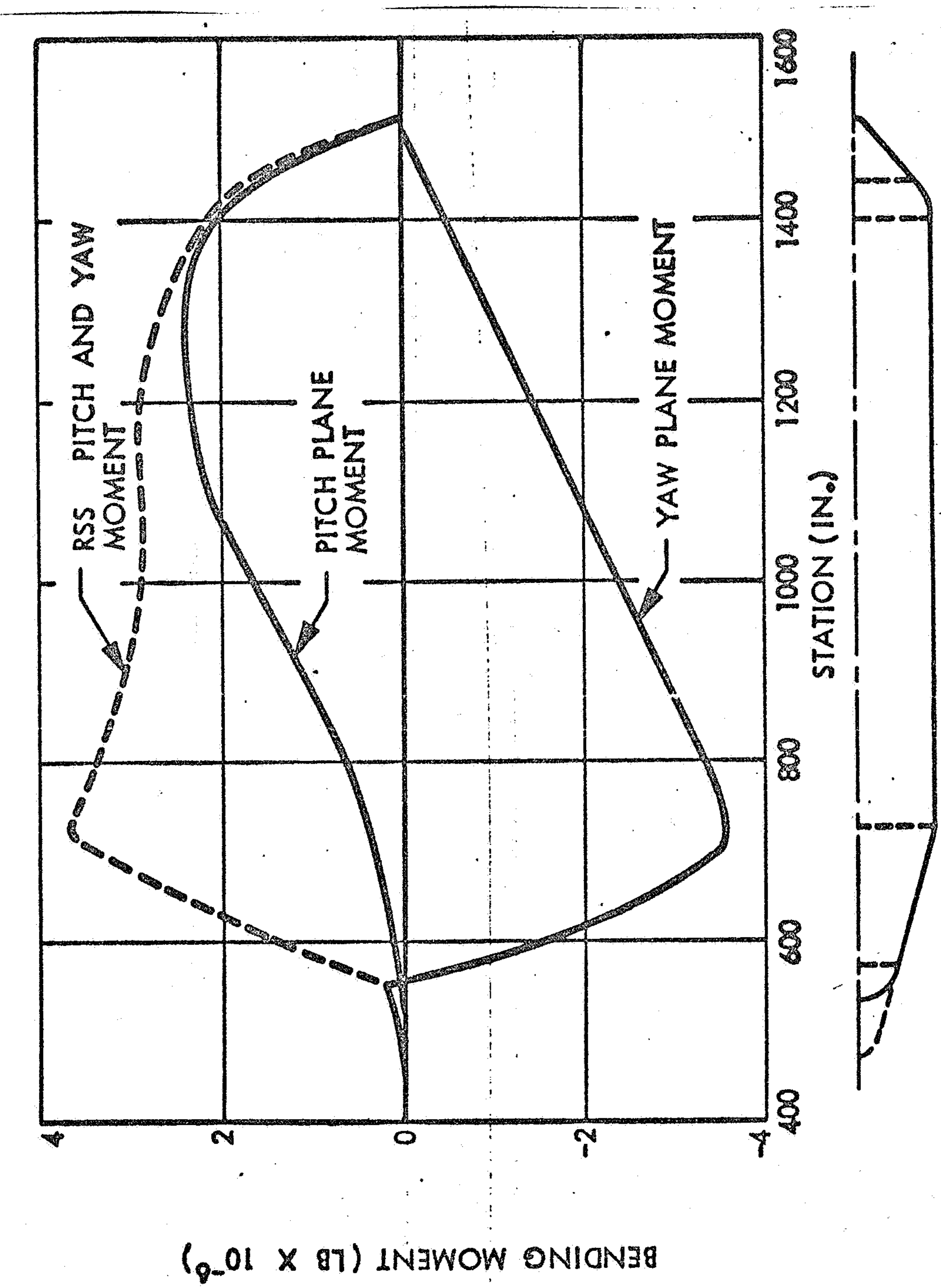

Fig. 10-1A

REVISED DROPTANK BENDING MOMENT
(BASED ON RECENT WIND TUNNEL DATA)

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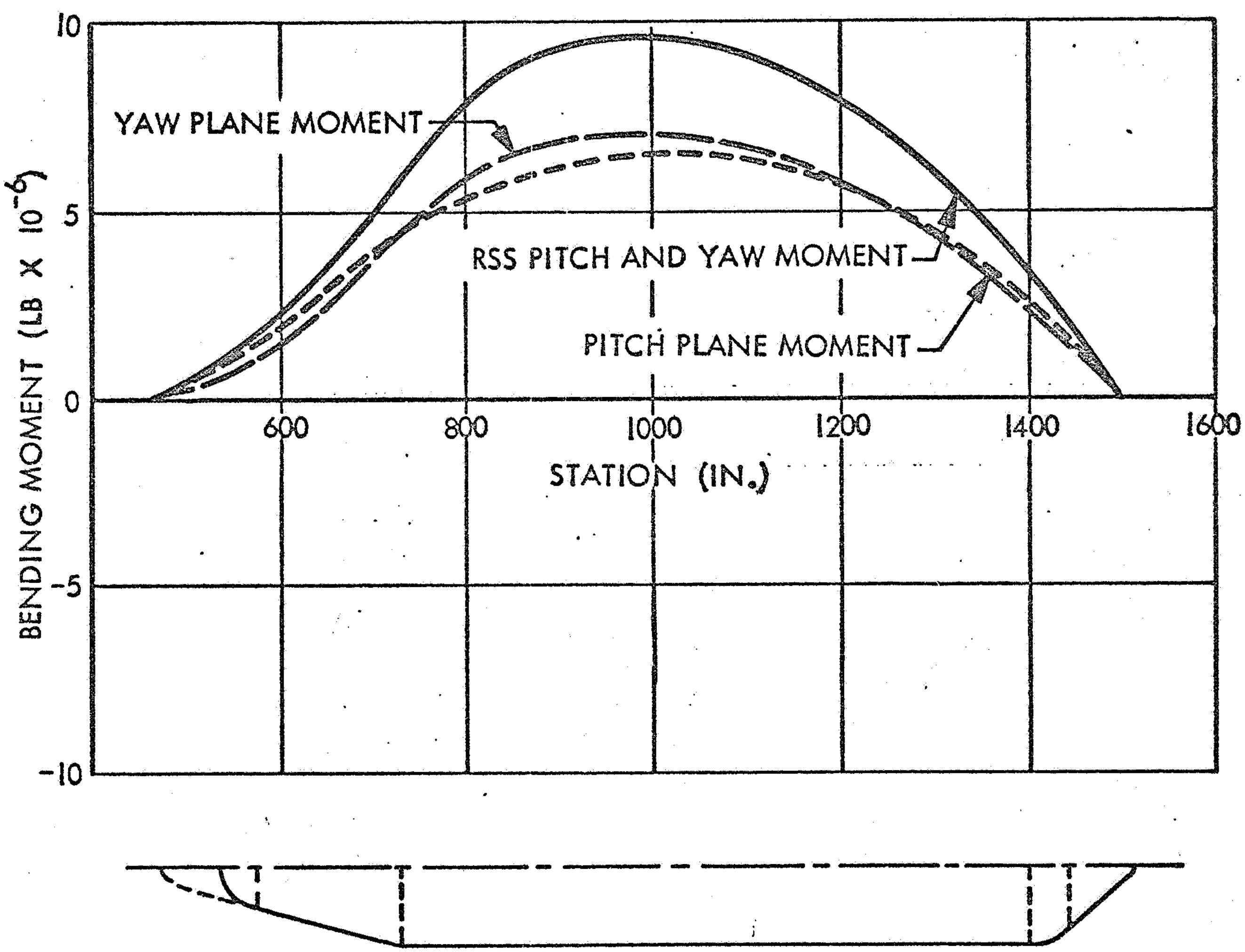

Fig. 10-1B

Fig. 10-1B

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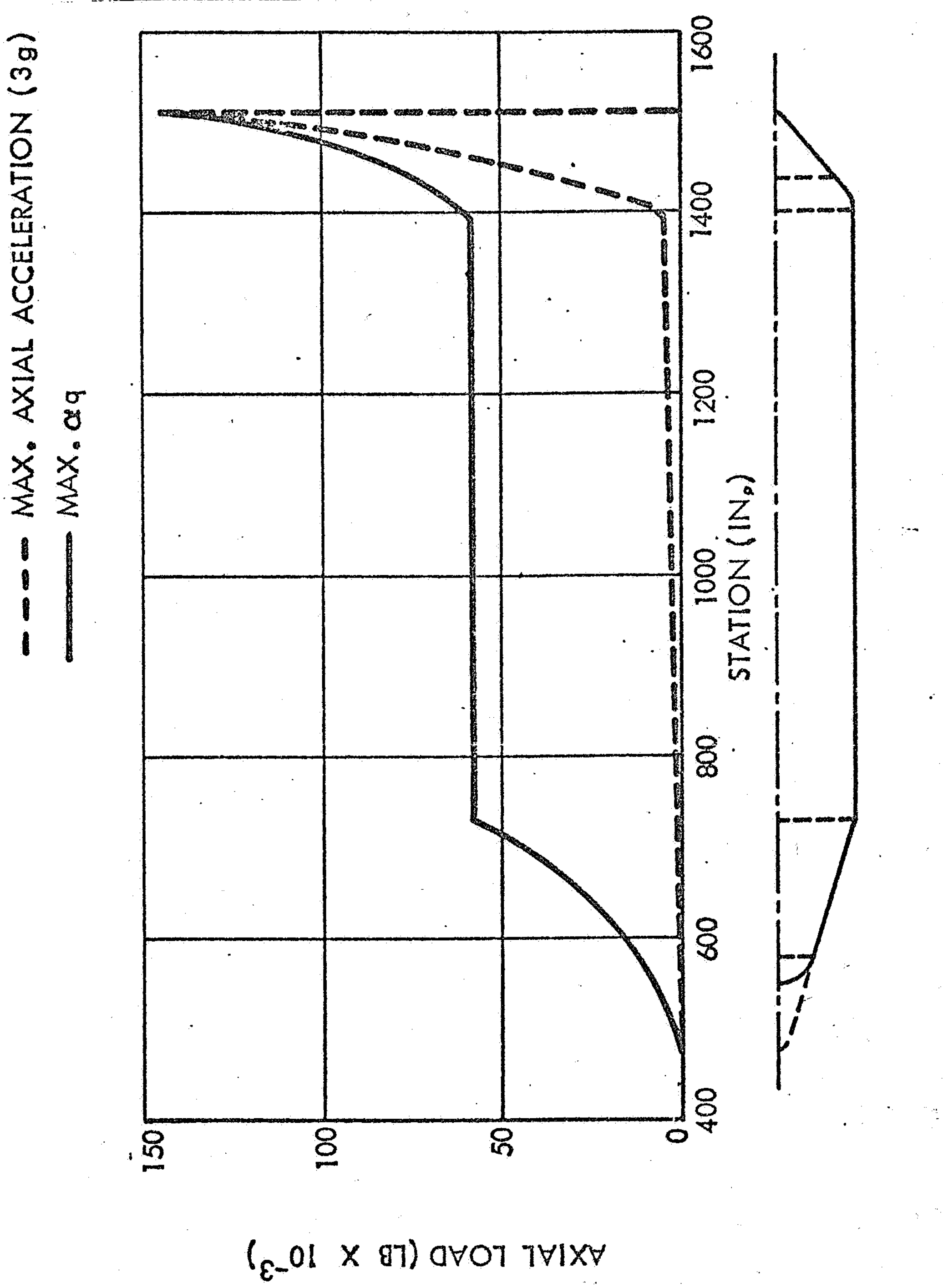


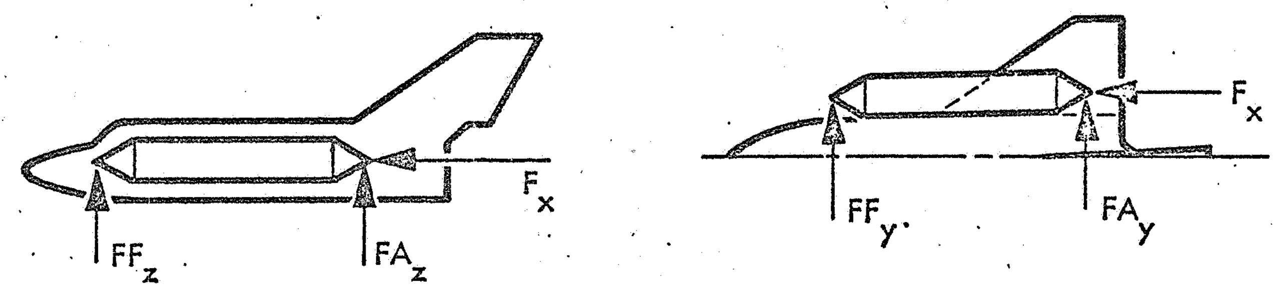
Fig. 10-2 Droptank Axial Loads

- LIFTOFF — NONCRITICAL
- MAXIMUM DYNAMIC PRESSURE

MAXIMUM αq, DEG-PSF	2000
LONGITUDINAL LOAD FACTOR, q	1.4
NORMAL LOAD FACTOR, q	0.4
DYNAMIC AXIAL LOAD FACTOR, q	0.3

- MAXIMUM AXIAL LOAD FACTOR, q — 3.0

TANK ATTACH REACTION CRITERIA



CONDITION	F_x (LB)	FA_z (LB)	FA_y (LB)	FF_z (LB)	FF_y (LB)
MAX AXIAL g	145,000	0	3,260	0	2990
MAX q	140,000	+16,000 - 9,960	±9,960	+9,440 -9,890	+ 9,440 -34,000

Fig. 10-3A Droptank Design Load Criteria

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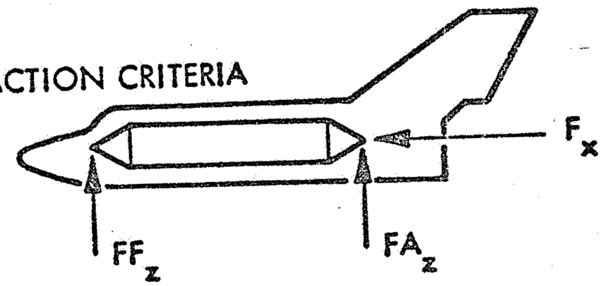
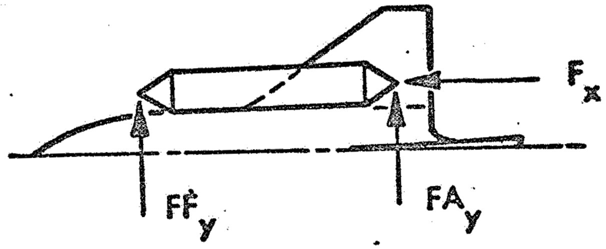
REVISED DROPTANK DESIGN LOAD CRITERIA

(BASED ON RECENT WIND TUNNEL DATA)

- LIFTOFF — NONCRITICAL
- MAXIMUM DYNAMIC PRESSURE
  - MAXIMUM αq, DEG-PSF — 2000
  - LONGITUDINAL LOAD FACTOR, g — 1.4
  - NORMAL LOAD FACTOR, g — 0.4
  - DYNAMIC AXIAL LOAD FACTOR, g — 0.3
- MAXIMUM AXIAL LOAD FACTOR, g — 3.0

TANK ATTACH REACTION CRITERIA





CONDITION	F_x (LB)	FA_z (LB)	FA_y (LB)	FF_z (LB)	FF_y (LB)
MAX AXIAL g's	-145,500	0	0	0	0
MAX + αq	-140,000	18,150	17,500	23,350	31,000
MAX - αq	-140,000	6,050	2,790	15,350	4,910
MAX + βq	-140,000	12,300	28,000	21,700	21,400
MAX - βq	-140,000	10,800	21,500	19,200	20,200

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Fig. 10-3B

Fig. 10-3B

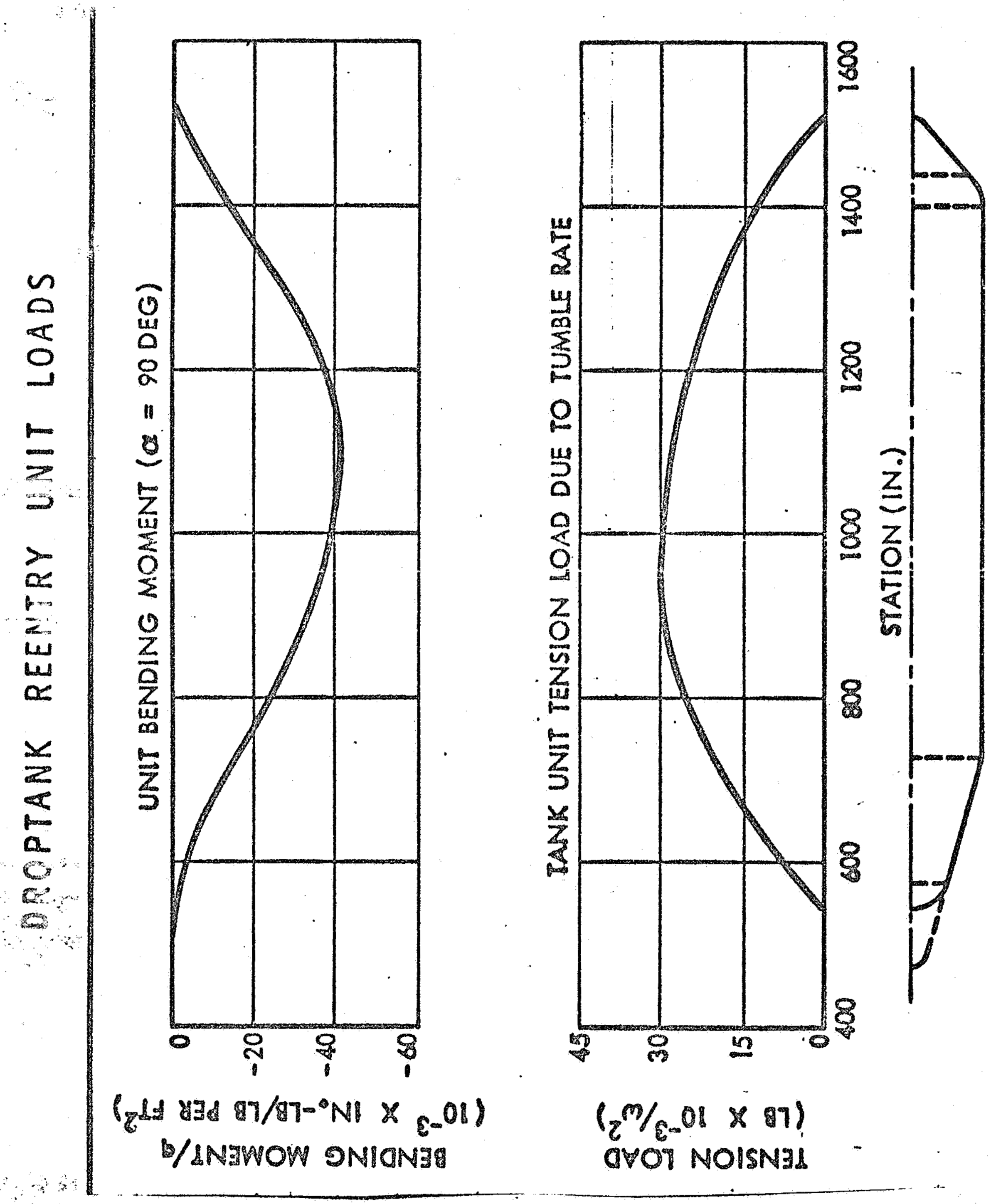

Fig. 10-4 Droptank Reentry Unit Loads

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DROPTANK REENTRY UNIT LOADS

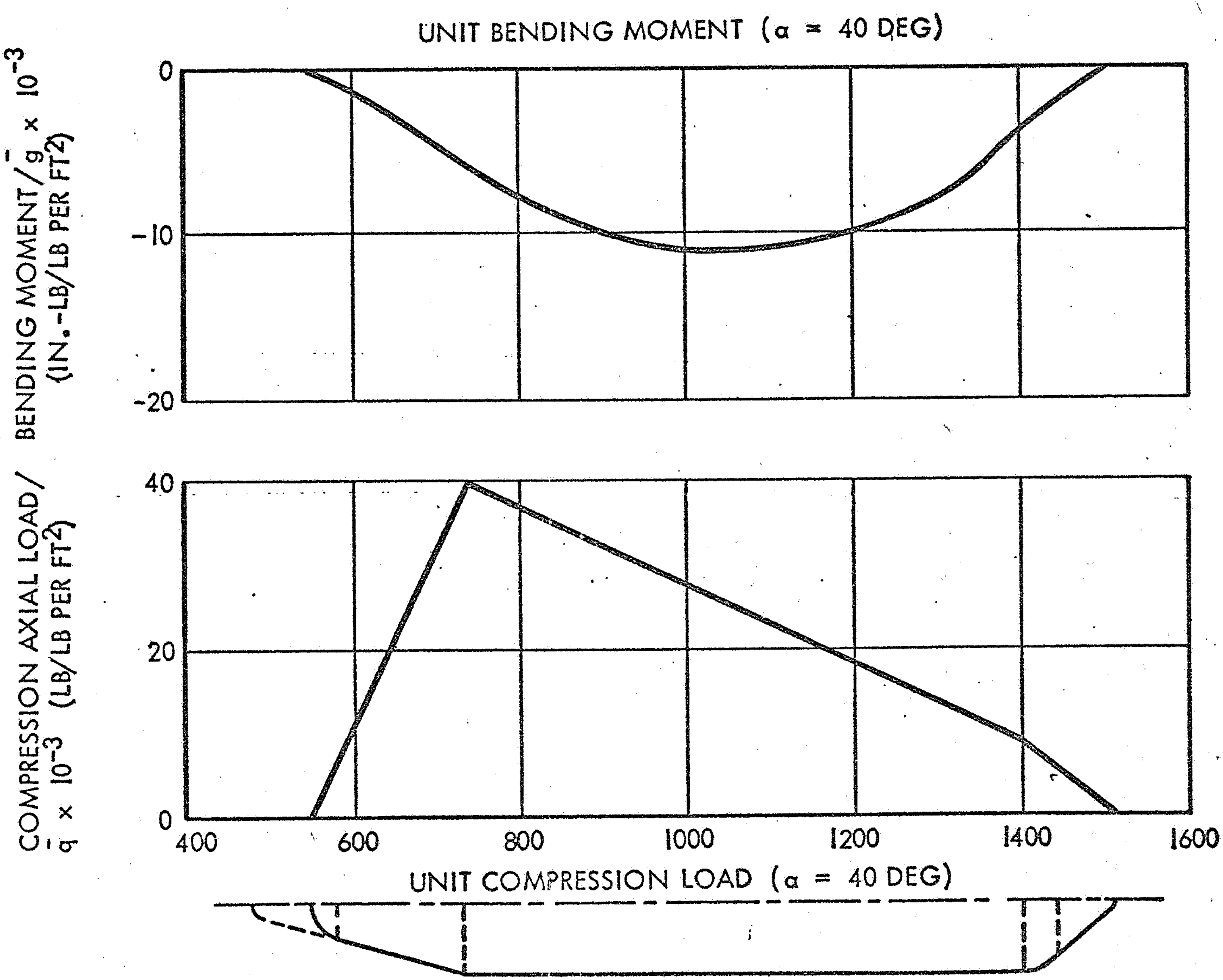

Fig. 10-5

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Fig. 10-5

10.2 DROPTANK STRUCTURAL ANALYSIS

The details of the analysis on which this section is based are contained in EM L2-12-01-13 (see Appendix).

10.2.1 Material Selection Criteria

Selection of a tank material is determined by strength and physical properties, metallurgical stability, and oxidation resistance. The screening of the various materials considered for the LH_2 droptank reduced to two primary candidates: 2219 aluminum and 301 stainless steel. These candidates were selected on the basis of high strength-to-density ratios, good-to-excellent fracture toughness, good weldability, and excellent compatibility with cryogenic fluids. Two tempers of 2219 aluminum were considered: T81 and T87. The T81 temper has slightly lower strength properties than the T87, but is available in wider sheets. A cost analysis established temper 81 to be cheaper for the fusion-welded configuration, whereas the weld-bond configuration makes use of temper 87. Details of the manufacturing aspects leading to this decision are discussed in Section 8. The extra-hard temper for 301 steel was also considered on a preliminary basis.

10.2.2 Droptank Structural Sizing

Preliminary tank membrane sizing is based on internal pressure requirements from launch release through separation. The criteria initially used for this study are based on the pressurization sequence provided by GAC. Table 10-1 summarizes these data, and presents the membrane weights for each of the baseline materials.

Table 10-1

DROPTANK SIZING CRITERIA

TANK MATERIAL	2219-T87 AL	2219-T81 AL	301 ST'L – EH.
ULTIMATE FACTOR OF SAFETY	D.O.	1.4	D.O.
VOLUME REQUIREMENT/TANK, FT^3		10,433	
PROPELLANT LOADING/TANK, LB		43,253	
ULLAGE VOLUME/TANK, FT^3		313	
ULLAGE PRESSURE:			
MAX. ACCELERATION (3g)		24.5	
ORBITER IGNITION (1.4g)		29.0	
DROPTANK BURNOUT		25.0	
TEMPERATURE (^oR):			
ULLAGE AREA (PRESSURIZATION GAS)		360	
WETTED WALL		40	
ULTIMATE STRENGTH (PSI):			
RT	63,000	62,000	188,000
360^oR	66,500	65,700	234,000
40^oR	94,500	94,200	316,000
TANK MEMBRANE WEIGHT, LB	1,852	1,870	1,555

Of the three design conditions, maximum acceleration proved not to be critical because of the higher ullage pressure occurring at orbiter ignition. A combination of the latter two conditions (orbiter ignition and burnout) established the membrane requirements. Minimum gage requirements were established at 0.025 and 0.010 for the aluminum and steel tank configurations, respectively. The resulting tank gages are shown in Table 10-2. Much of the steel configuration resulted in a design for minimum gage, whereas only the tank domes are designed for minimum gage on the aluminum configurations. Orbiter attachment loads require the aft cone section to be thickened beyond the values indicated here. The design drawing Fig. 9-1 show these details. This area is discussed separately.

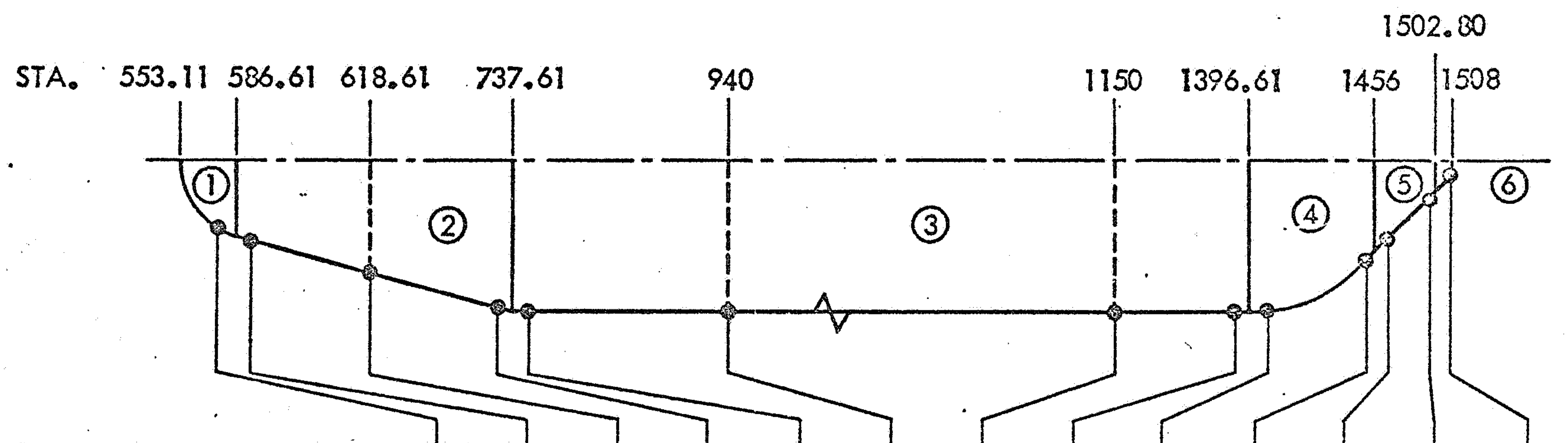
Establishing gage requirements for the empty tank condition (burnout) assumes that a linear temperature drop occurs from the top to the bottom of the tank. This assumption was checked by a thermal analysis, and good agreement results, as shown in Fig. 10-6.

Having established gage requirements for internal pressure, a check on ascent load capability was performed to determine whether that consideration is critical to the design. The ascent axial load and bending moment occurring at maximum $\alpha\bar{q}$, discussed previously in Section 10.1, results in the most severe ascent load condition. Converting these to maximum compression stress resultants (line loads) and comparing them to the structural capability of the membrane while at maximum αq (ambient pressure is 5.3 psi), shows that the tank is not critical in this environment. For this condition, the tank internal pressure is assumed to be 3 psi lower due to valve tolerance considerations. This comparison is shown in Fig. 10-7.

These results plainly show that the droptank can be sized and/or optimized using internal pressure considerations. Structural trade studies were pursued, therefore, to evaluate the weight penalties associated with proof-test considerations, ground handling, and variations in ullage pressure. These results are discussed in later paragraphs.

Table 10-2

BASELINE DROPTANK MEMBRANE SIZING



THICKNESS (IN.)	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}
2219-T-87 FLT COND (INT PRESS.) WT = 1852 LB	.025	.028	.033	.045	.044	.042	.039	.040	.025	.025	.040	.025	.025
2219-T-81 FLT COND (INT PRESS.) WT = 1870 LB	.025	.028	.034	.046	.044	.043	.040	.040	.025	.025	.040	.025	.025
301 CRES EXTRA HARD FLT COND (INT PRESS.) WT = 1555 LB	.010	.010	.010	.012	.012	.012	.012	.012	.010	.010	.012	.010	.010

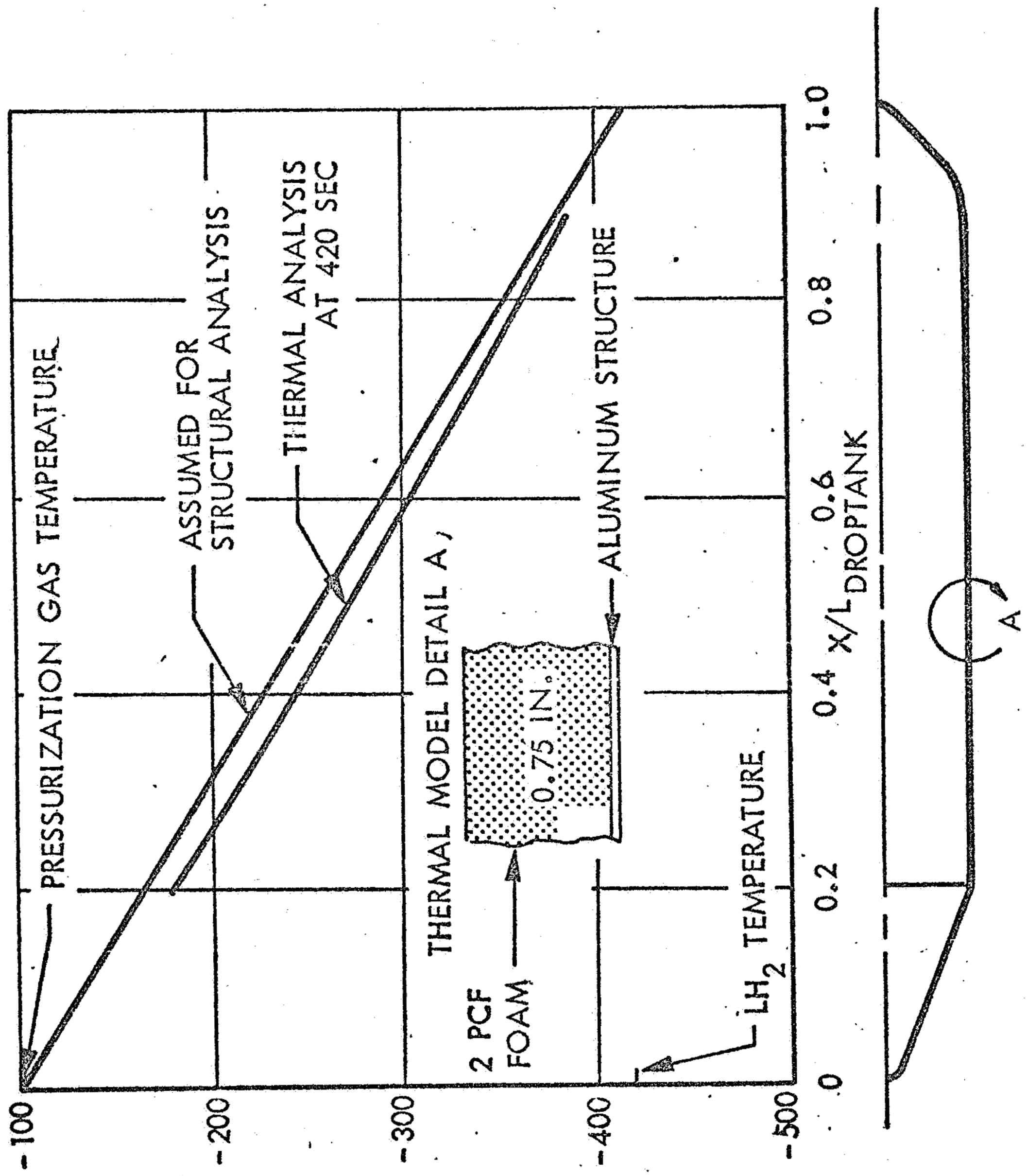


Fig. 10-6 Droptank Critical Structure Temperature

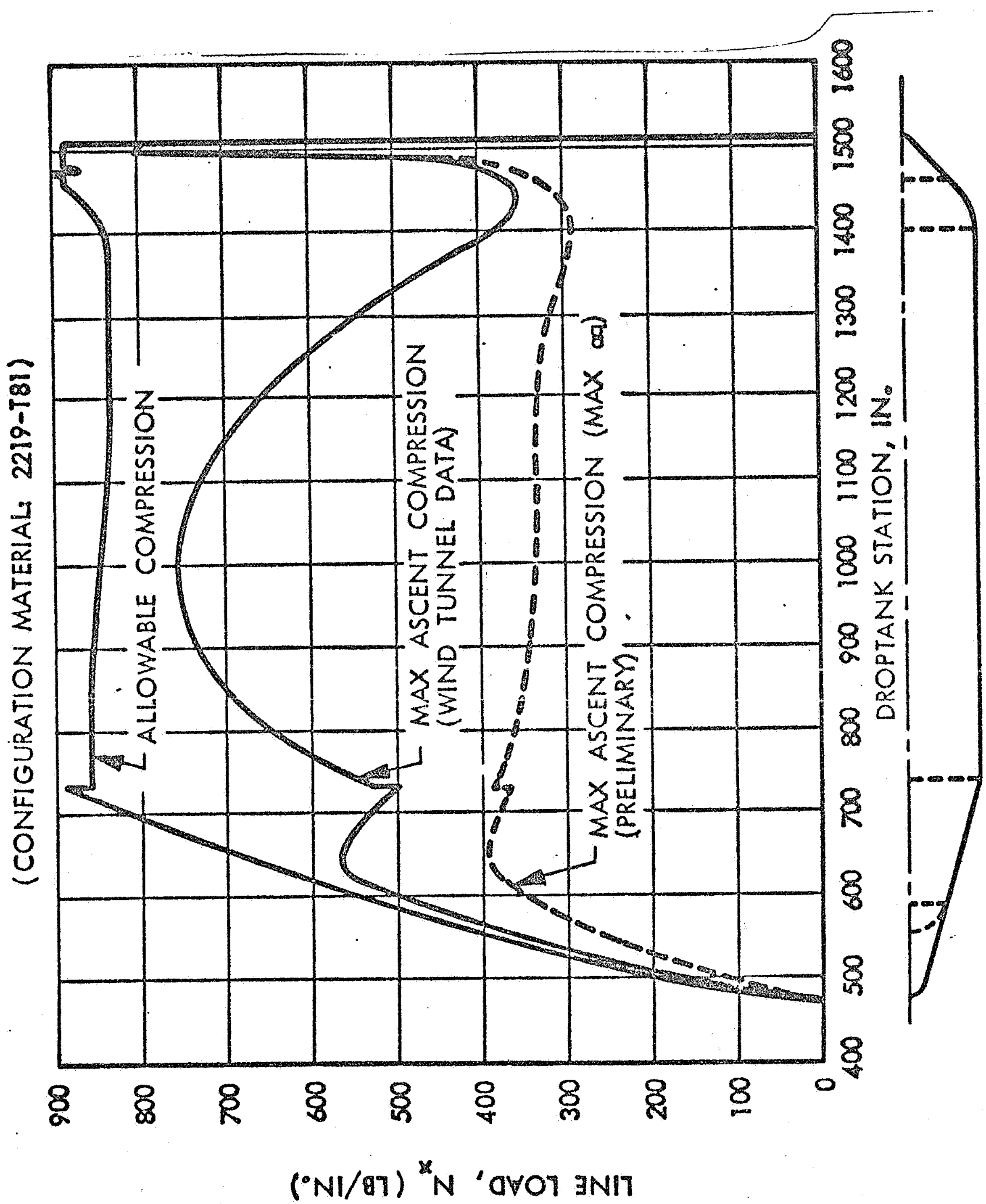


Fig. 10-7 Droptank Ascent Compression Line Load

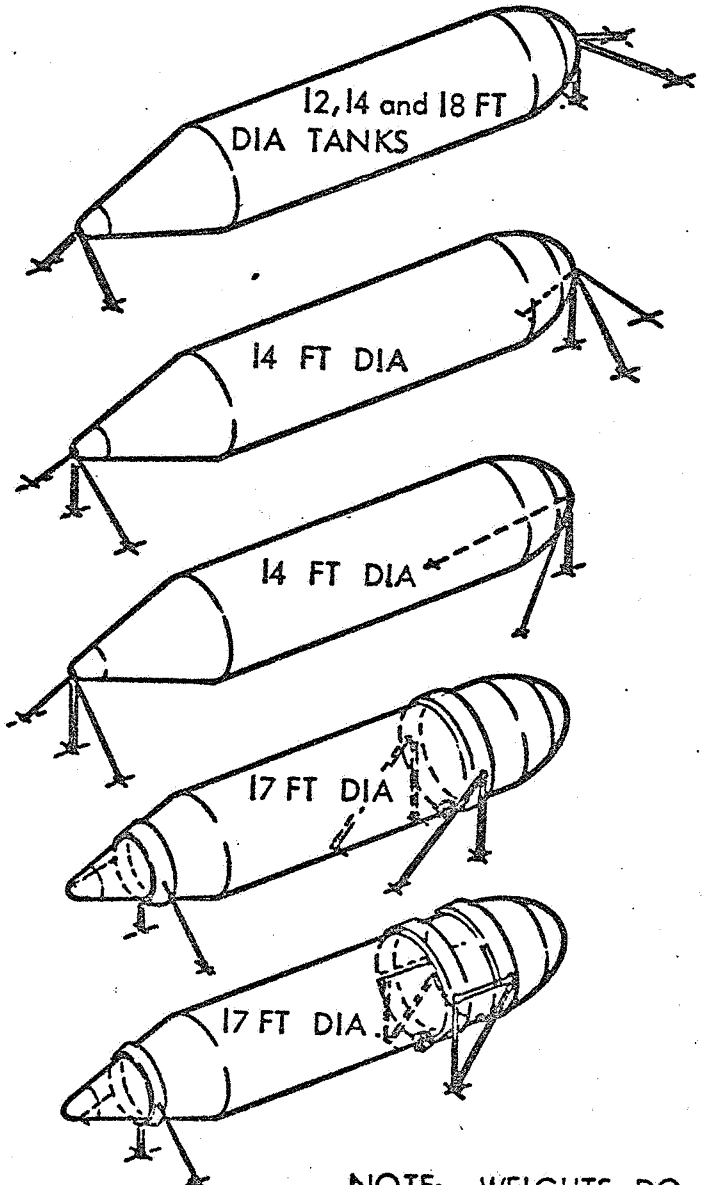
10.2.3 Droptank Support Structure

To minimize weight, 6AL-4V titanium was selected for all five configurations shown in Fig. 10-8. The support configuration identified as Configuration 1 (two members at front and three aft with the drag strut under compressive loads) was used to analyze the weight impact for three different tank diameters (12 ft, 14 ft, and 18 ft). Results of this analysis are shown in Fig.10-9. It should be noted that Configuration 1 requires using tubular members with column capability for all struts. To minimize weight, a configuration using the combination of tension and compression members (rods) was considered. Using this approach, two configurations (Configurations 2 and 3) were studied for the baseline tank (14 ft dia) and two (Configurations 4 and 5) for the GAC tank (17 ft dia). The resulting weights, also plotted in Fig. 10-9, clearly show the advantage of the tension drag struts (rods) approach. The weights shown in Fig. 10-9 do not include member end fittings. The analysis performed on all configurations uses loads taken from EM L2-12-01-M1-12 (see Appendix), and assumes all members to be pin ended at frictionless rigid joints.

The analysis of Configuration 1 (baseline approach) for three different tank diameters was facilitated using a computer program, whereas, Configurations 2 through 5 were analyzed by hand and minor simplifying assumptions were made. (Refer to EM L2-12-01-M1-13 for detailed analysis.)

10.2.4 Droptank Shroud Analysis

The droptank shroud design is a function of the design requirements. Initially, its purpose was to support a small rocket, used for entry. Later design alternates show the rocket motor supported from the aft cone of the droptank. Initially, the cone analysis was based on the criteria and geometry shown in Fig. 10-10. The purpose of this trade study was to establish weights for two candidate materials and two structural concepts. The weight results shown in Fig.10-10 indicate that significant weight savings are achieved using magnesium HM21A-T8. From this study, it was therefore concluded to use HM21A-T8 as the baseline material for the nose shroud. However, more recent study results



CONFIG. 1 BASELINE DROPTANK
(ALL TUBULAR MEMBERS)
WEIGHT FOR 14 FT DIA = 259 LB.

CONFIG. 2 BASELINE DROPTANK
(TWO TUBES AND FIVE RODS) WEIGHT = 118 LB

CONFIG. 3 BASELINE DROPTANK
(TWO TUBES AND FOUR RODS) WEIGHT = 93 LB

CONFIG. 4 GAC DROPTANK
(THREE TUBES AND FOUR RODS,
ONE RING AT TANK) WEIGHT = 136 LB

CONFIG. 5 GAC DROPTANK
(FRONT SUPPORT SAME AS CONFIG.
4, AFT SUPP. REQUIRES TWO RINGS AND
INTERCOSTAL AT TANK). WEIGHT = 148 LB

NOTE: WEIGHTS DO NOT INCLUDE FITTINGS, RINGS, AND NOF

Fig. 10-8 Droptank Support Configurations

LH_2 TANK STRUT WEIGHT

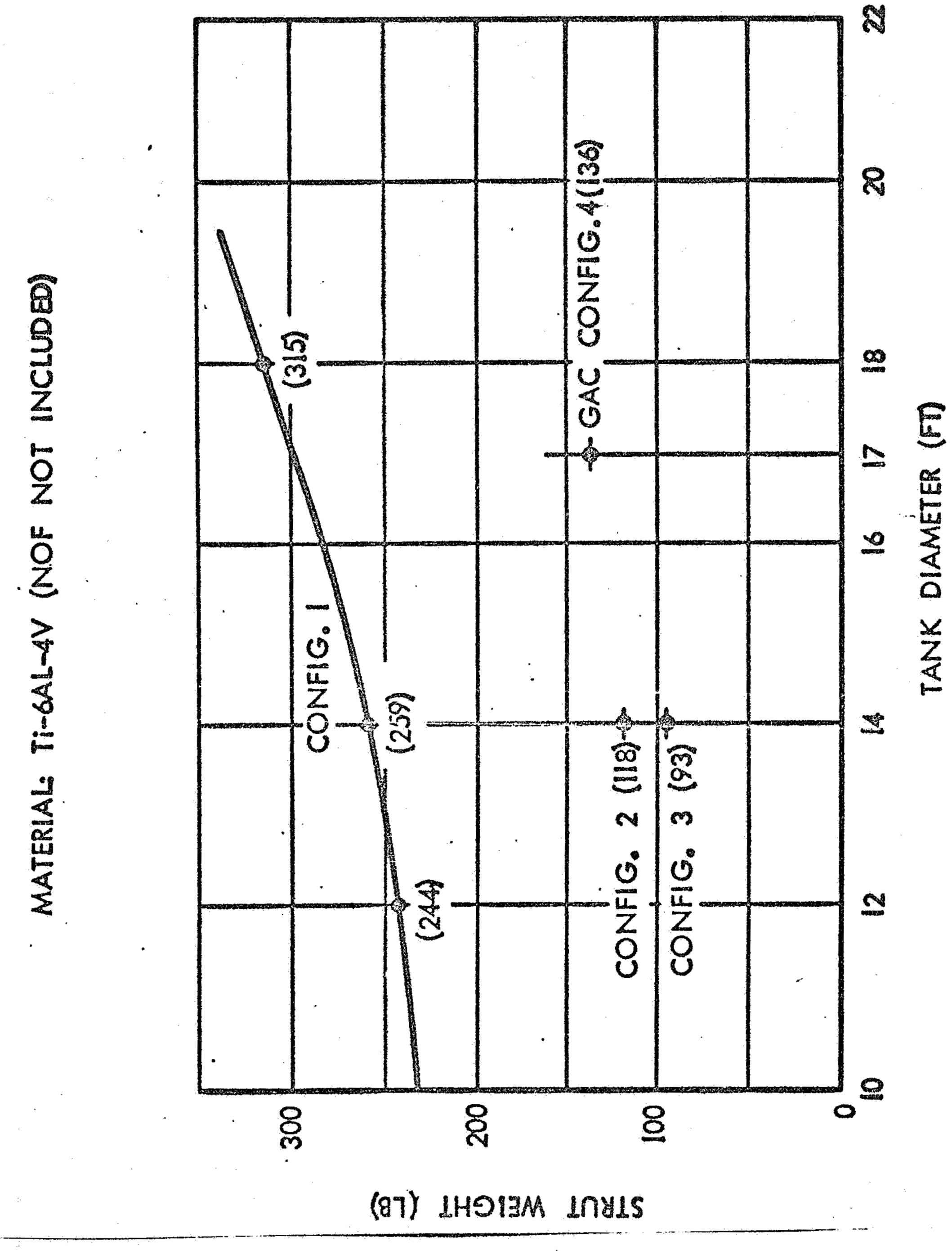
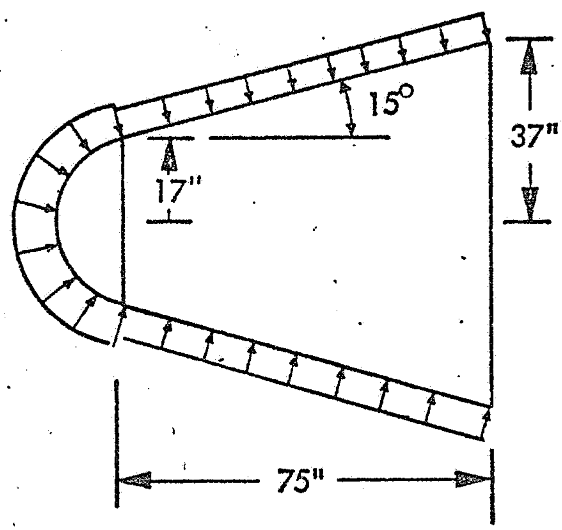


Fig. 10-9



- FACTOR OF SAFETY 1.4
- DESIGN TEMPERATURE 300°F
- DESIGN LIMIT PRESSURE (MAX αq):
  - NOSE CAP 3.5 PSIG (STAGNATION)
  - CONE 2.6 PSIG
- CAP DESIGN (MONOCOQUE SHELL):
  - ALUMINUM 2219-T87, THICKNESS = 0.030 IN.
  - MAGNESIUM HM21A-T8, THICKNESS = 0.039 IN.
- CONE DESIGN:

MATERIAL	CONCEPT	$\bar{t}$ (IN.)	WEIGHT (LB)
2219-T87 AL	MONOCOQUE	0.130	175
2219-T87 AL	RING-STIFFENED	0.051	68
HM21A-T8	MONOCOQUE	0.159	134
HM21A-T8	RING-STIFFENED	0.060	51

Fig. 10-10 Droptank Forward Shroud

show sitka-spruce plywood to be more cost effective, and so the final baseline design, presented in Eng Dwg SKM 100117, (Fig. 9-3) has a monocoque wooden nosecap attached to a chem-milled ring-stiffened cone frustum, which is mechanically fastened to the forward stub skirt of the droptank. This design accounts for the rocket support structure, as well as the ascent load requirements.

10.2.5 Aft Thrust Cone Analysis

The LH_2 tank is supported on a bolted flange at its aft end, as shown in Fig. 10-11. The concentrated support loads, although to some degree alleviated by the internal pressure, create relatively high compressive stresses which may cause the shell to buckle or collapse elastically before the ultimate strength of the material is reached. The geometry and loadings are complex, requiring a relatively sophisticated analysis.

Three different analyses were performed, using the computer code BOSOR (Ref. 11-1):

1. Linear, nonsymmetric stress analysis
2. Linear buckling analysis for nonsymmetric loading
3. Nonlinear, axisymmetric collapse analysis

It was found that the shell will buckle elastically at 1.33 times the ultimate load according to the classical buckling theory. Accounting for a conservative practical "knock-down" factor (Ref. 11-2), this figure is reduced to about 0.83; therefore, for the preliminary baseline design, the cone thickness was increased to 0.060 in. at the juncture with the forward spherical section, and then tapered to the 0.150 thickness indicated in Fig. 10-11. This change will increase the buckling load to that required to resist the ascent loads. The details of this analysis are presented in EM L2-12-01-M1-14 (see Appendix).

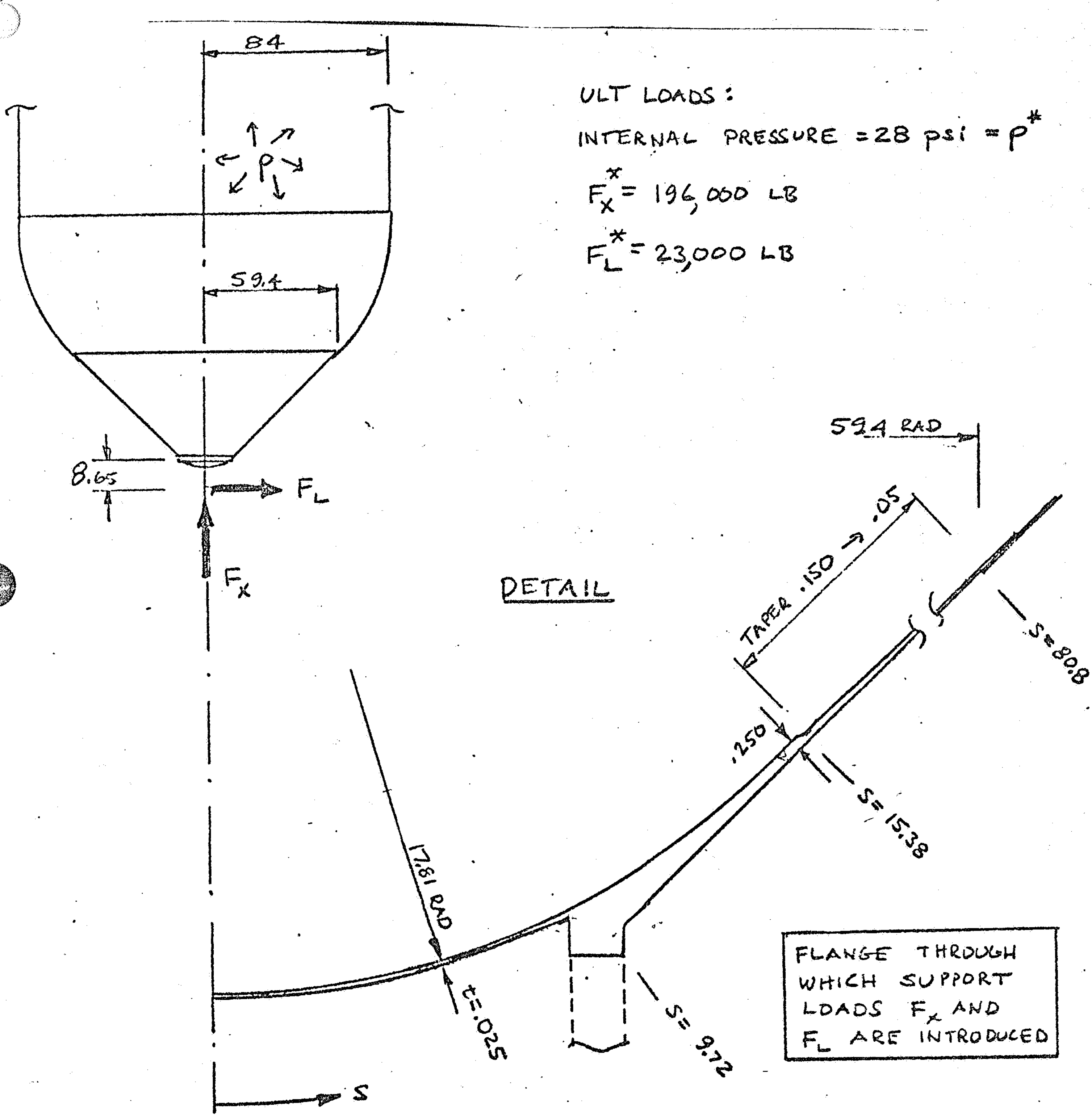


Fig. 10-11 Aft End Configuration, LH_2 Tank

10.2.6 Weld-Bond Joint Analysis

This study considered two production techniques for fabricating the droptanks: the fusion-welded tank and the weld-bonded tank. Analysis of fusion-welded tanks is straightforward and needs no formal discussion. The weld-bond process, however, is a relatively new process which combines adhesive bonding with spotwelding to form a joint that is very efficient, strong, and crack-resistant. LMSC has proposed to use this type of joint fabrication for droptank production. To provide credibility to the design of this configuration, a brief design-stress analysis of this joint was conducted. Using the computer code BOSOR (Ref. 11-1), stress analysis, including the very significant nonlinear effects, was performed for several variations of the joint design shown in Fig. 10-12. The analysis shows that the omission of nonlinear effects would underestimate the ultimate pressure capability of the LH_2 tank by more than 300 percent. Typical results for one of the design configurations are shown in Fig. 10-13. Based on the preliminary results of this analysis, the recommended joint for weld-bonded tanks is as shown in Fig. 10-14.

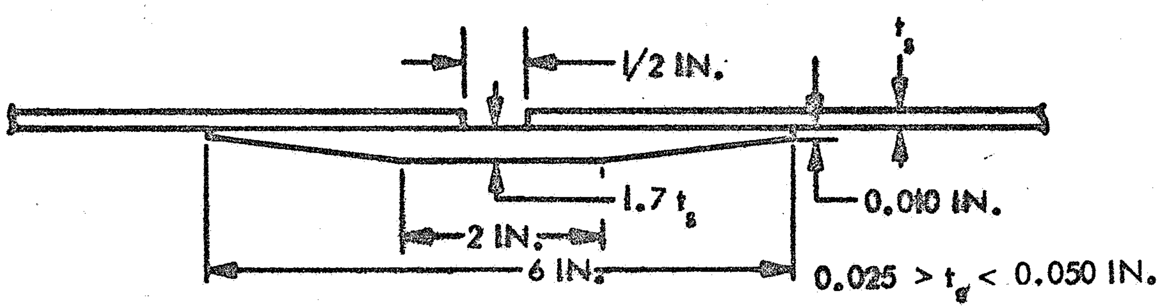


Figure 10-14 Design Configuration – Weld-Bond Joint

The details of this analysis are presented in EM L2-12-01-M1-15 (see Appendix).

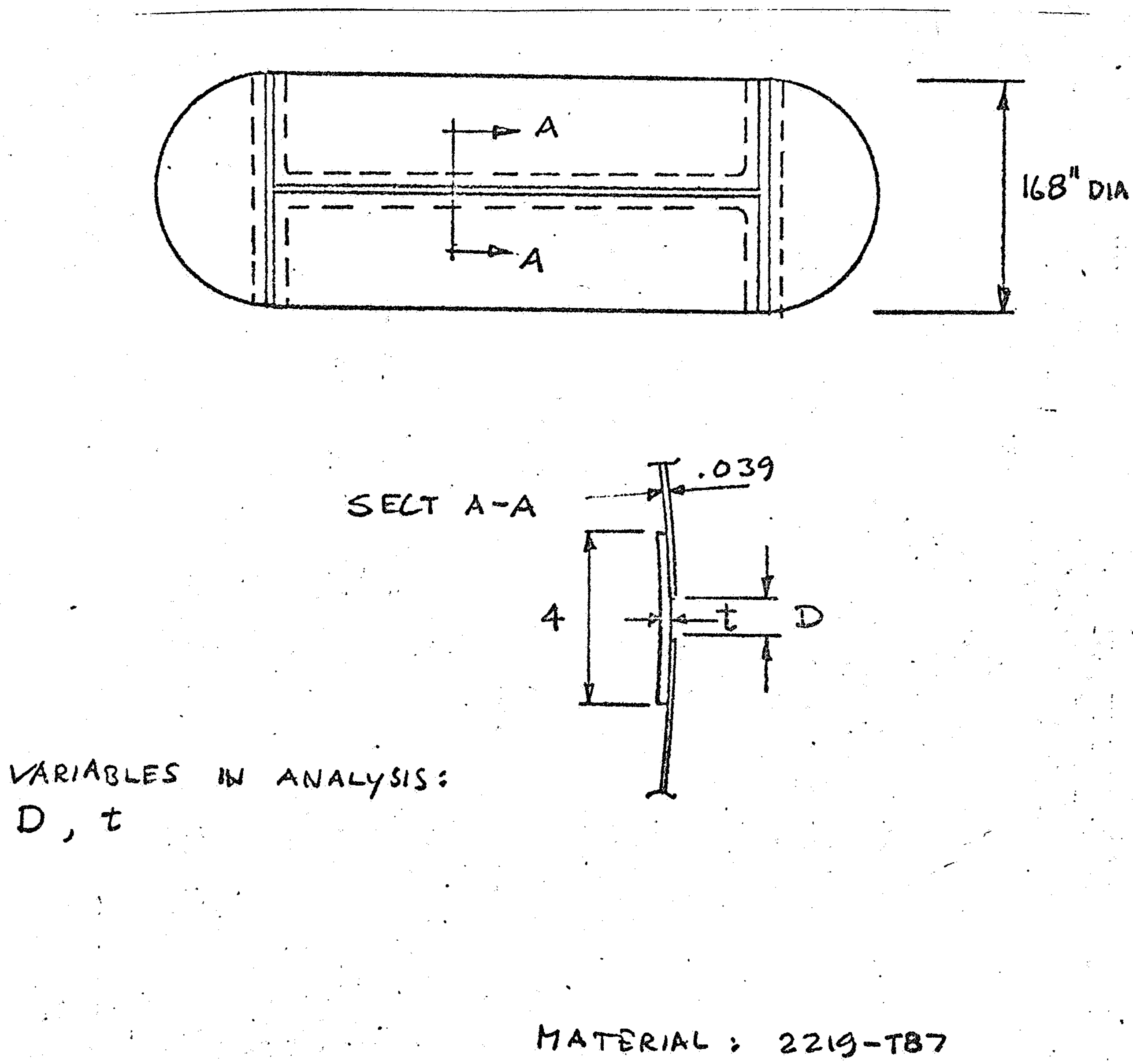


Fig. 10-12 Strap Joint in LH_2 Tank

LONGITUDINAL STRAP JOINT NONLINEAR ANALYSIS

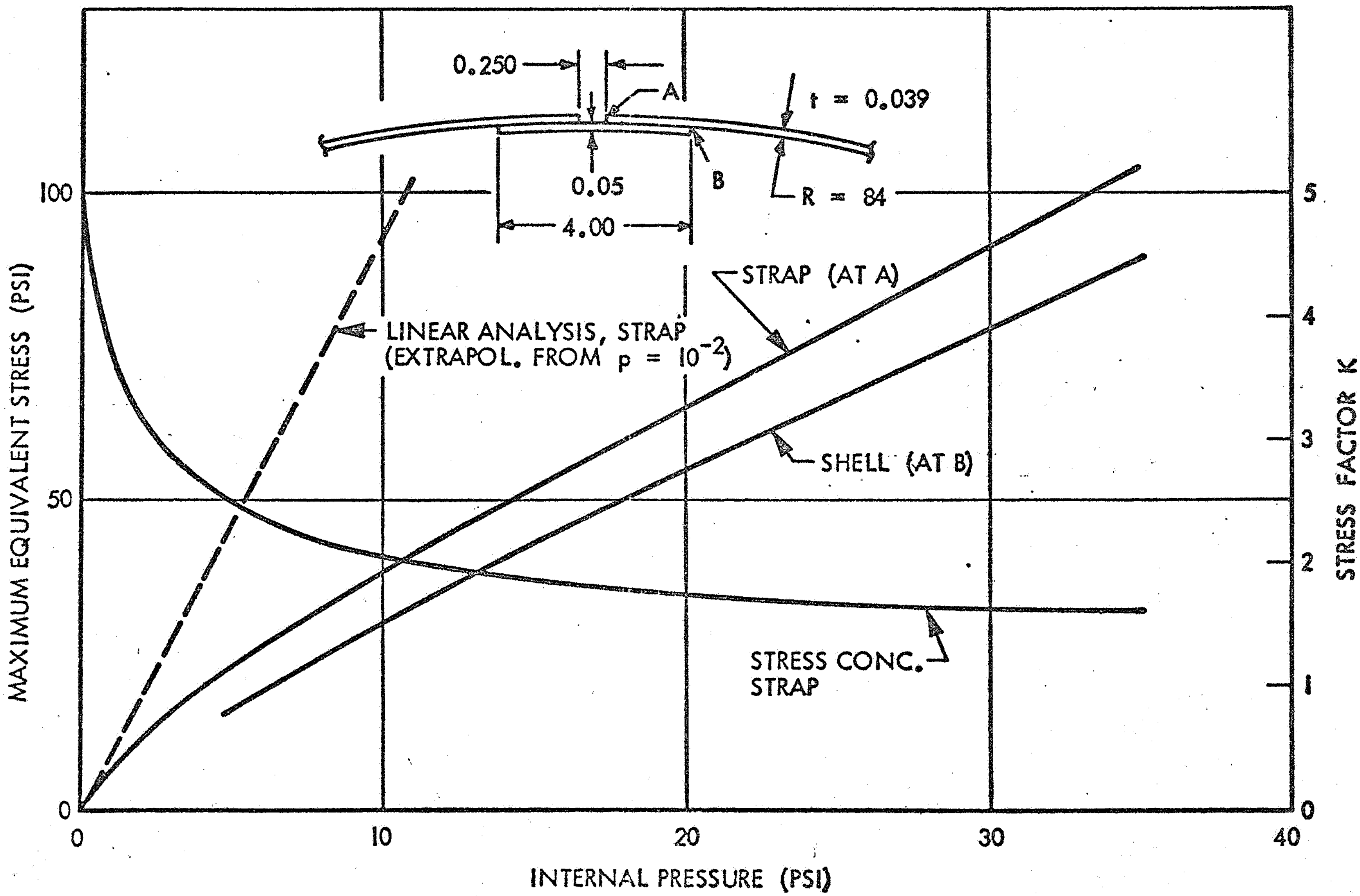


Fig. 10-13

Fig. 10-13

10.3 INTACT ENTRY STRUCTURAL ANALYSIS

Using the membrane wall thicknesses established for ascent internal pressure requirements for the 2219-T81 aluminum configuration (see Fig. 10-7), a structural analysis was performed to determine the droptank structural capability during intact entry as a function of tank wall temperature and internal pressure. Figure 10-15 presents the burst strength capability for discrete locations along the droptank as a function of tank wall temperature. It can be seen from this figure that if the droptank is vented to a low internal pressure, the allowable wall temperature can be quite high. For example, venting the tank to 8 psia, limits the wall temperature to 620°F. Calculations for allowable compression and tension line loads were performed for several values of tank internal pressure. For compression loads, a valve pressure tolerance of 3 psia was used. The resulting allowables for the tank are shown in Figs. 10-16 and 10-17. The tension side of the droptank establishes the limiting wall temperature at pressure.

Since the purpose of this analysis is to determine the minimum insulation requirements for entry, the allowable loads must be compared to loads the tank will experience during entry. Two conditions were used. Before 6-D trajectory analysis results were available, the droptank was assumed to have a tumbling trajectory, at a rate of 0.6 radians per second. Preliminary trajectory analysis indicated that the maximum dynamic pressure for this condition never exceeds 70 psf. Since these trajectory analyses were incomplete at the time of loads and structures analysis, a $\bar{q}$ of 100 psf was selected for initial investigation. After completion of the trajectory analyses, the results showed that the droptank trims, nose first, to a maximum angle-of-attack, α, of 40 deg, and the maximum dynamic pressure reaches 630 psf. The loads from both these conditions (shown in Figs. 10-4 and 10-5) were converted to maximum line loads in compression and tension and superimposed on Figs. 10-16 and 10-17 for comparison with the allowable tank line loads. It is readily seen that the maximum entry loads are not critical if the tank wall

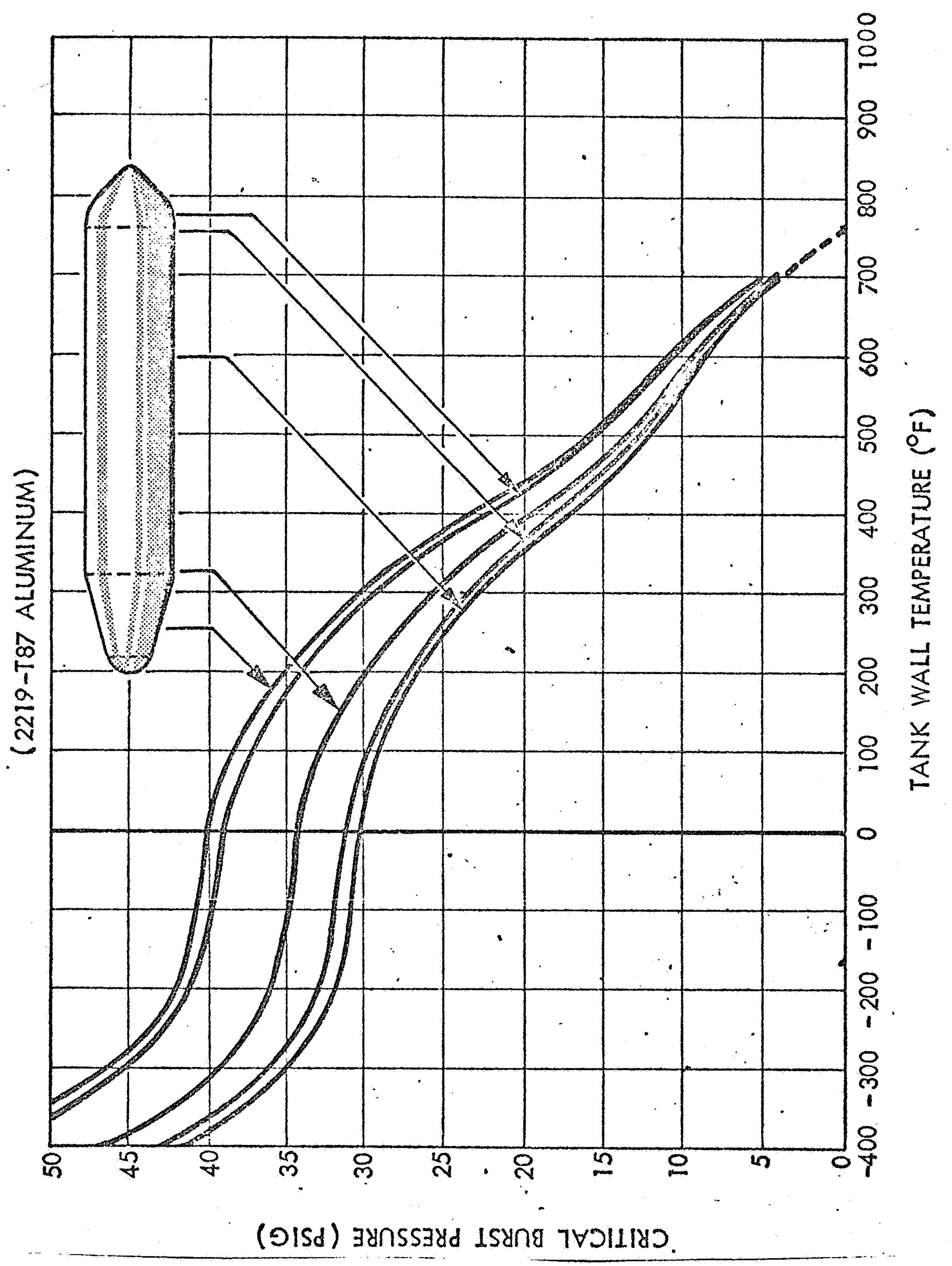


Fig. 10-15 Droptank Critical Burst Pressure

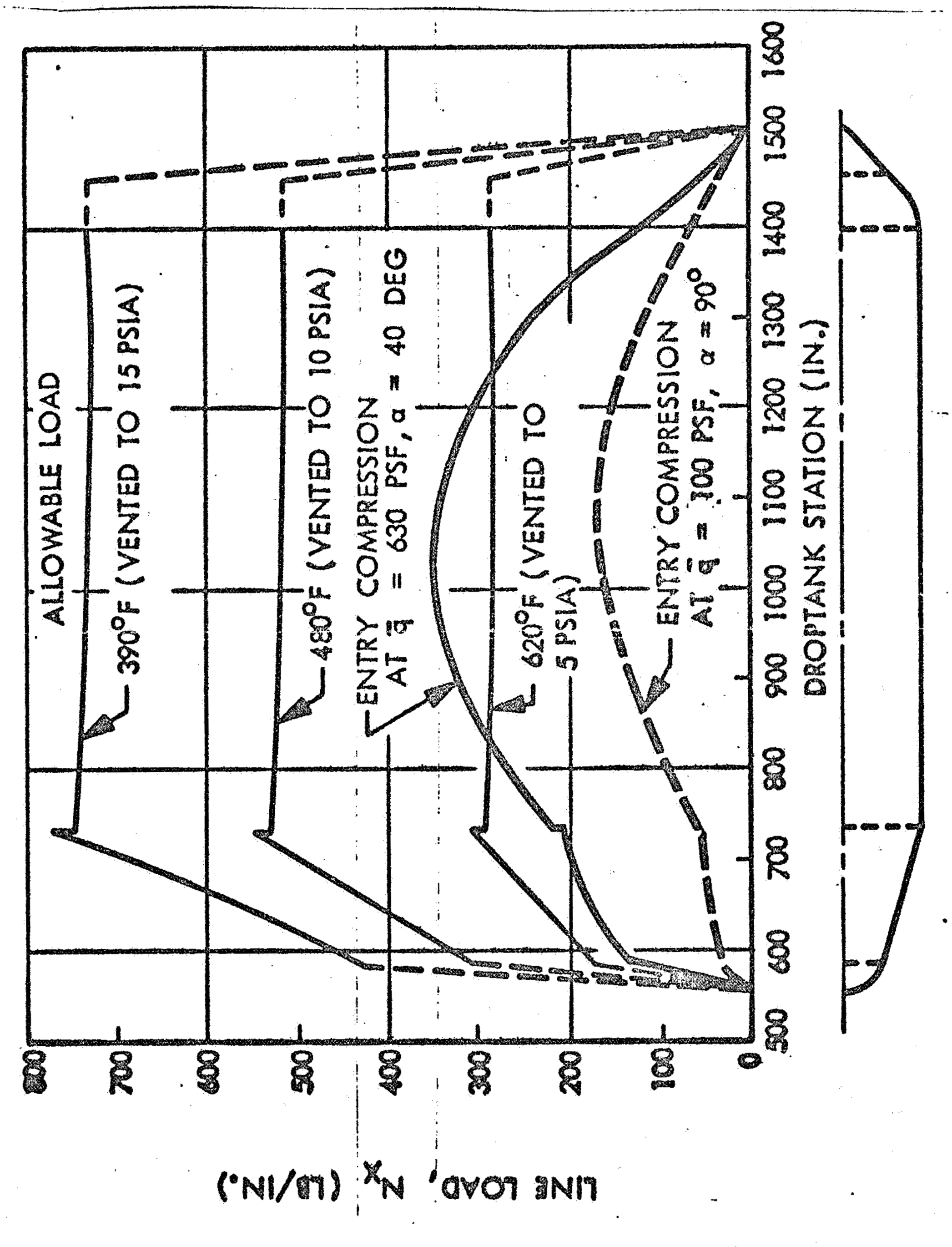


Fig. 10-16 Droptank Entry Compression Line Load

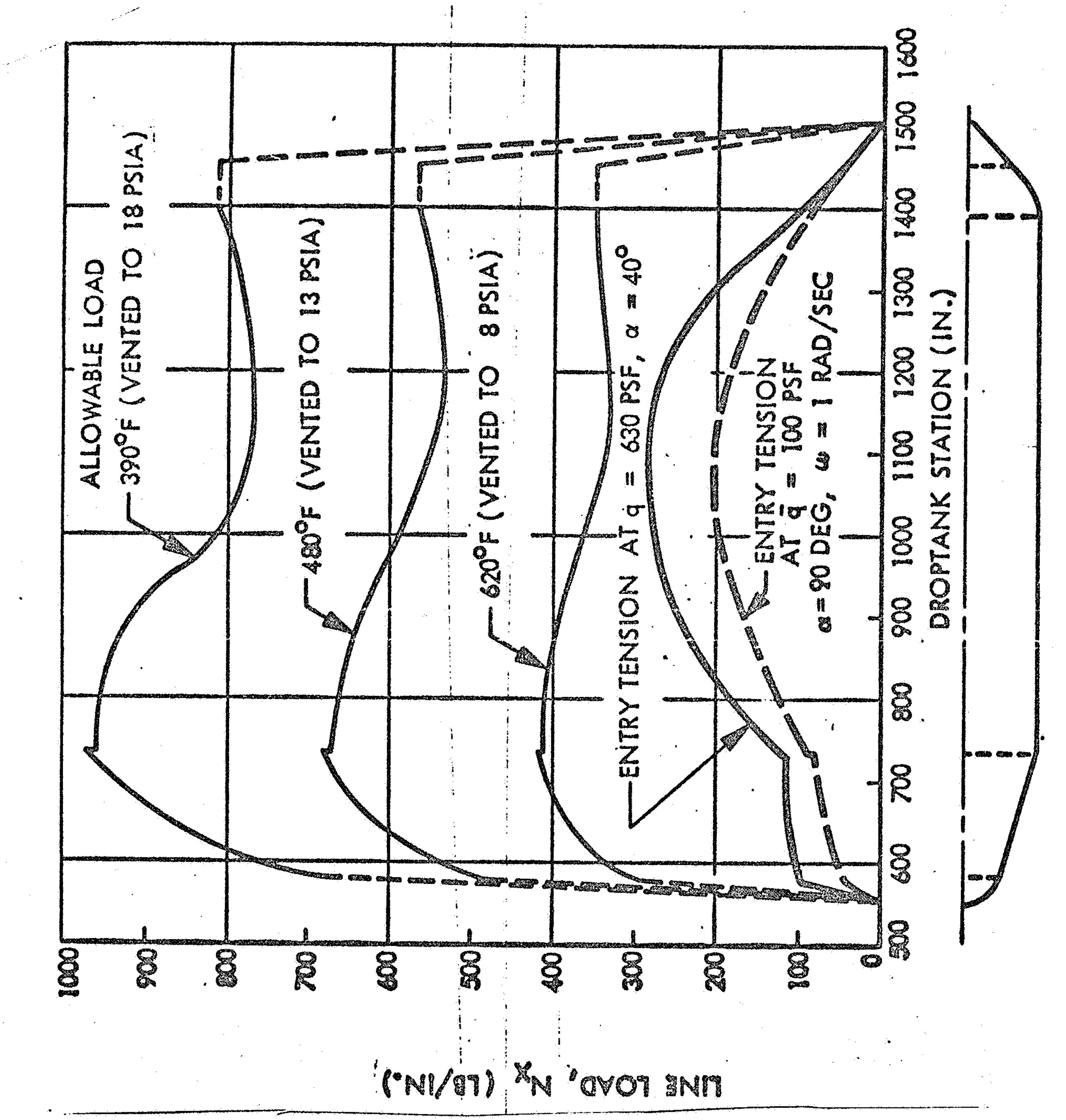


Fig. 10-17 Droptank Entry Tension Line Load

temperature is limited to 500°F by cork insulation. The temperature 500°F was selected on the basis of the temperature limitations of the bonding agent. Thus, intact entry can be achieved to an altitude of 13,000 ft, before collapse occurs when ambient pressure becomes greater than the vented tank pressure which is set at 12 psia $^{+0}_{-3}$. The details of this analysis are presented in EM L2-12-01-M1-13 in the Appendix.

10.4 OTHER DROPTANK CONSIDERATIONS

10.4.1 Proof Test Considerations

Proof testing a pressure vessel designed for a variety of design environments becomes a difficult problem. The droptank critical design environment is a complex one because the critical condition occurs when the tank is empty, and the tank wall temperature varies linearly from 360°R (pressurization gas temperature) to 40°R (LH_2 temperature). At this condition, the tank pressure is constant; in this case, 25 psia. Compromising any part of this environment will detract from the validity of the proof test and may cause a weight penalty.

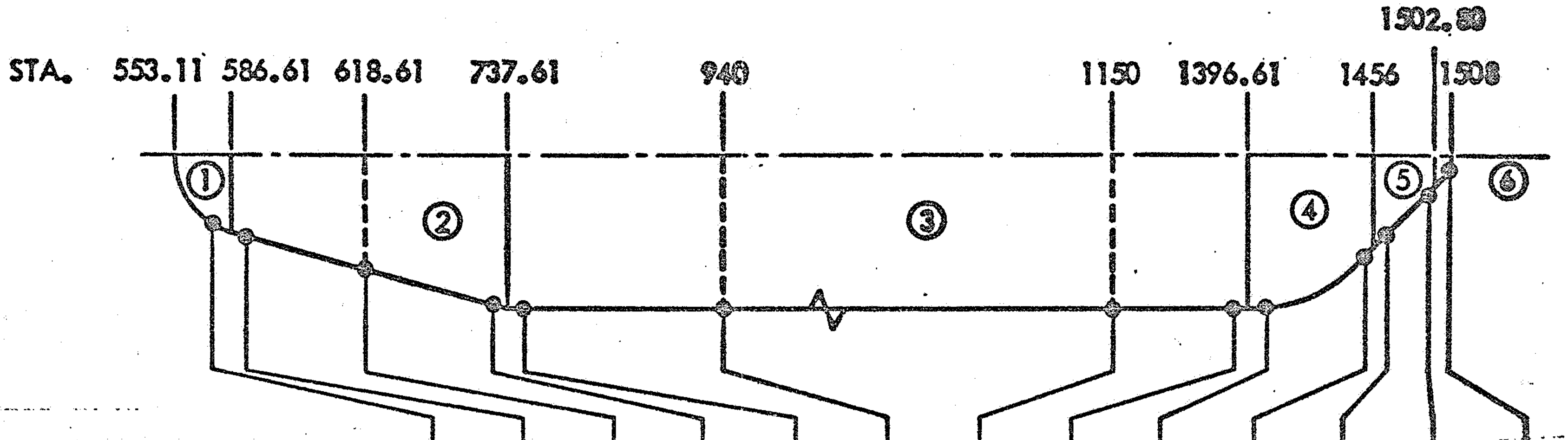
The simplest approach to proof testing pressure vessels is a pneumatic pressure test. Table 10-3 shows the tank gage increases that are necessary if an equivalent proof pressure is established for one critical tank location. In this case, the critical location selected is Station 680. Comparing these gage values to those established for the true environment (see Table 10-2), it is noted that a severe weight penalty results for both candidate materials. These weight penalties are based only on theoretical dimensions, and thus increase another 35 percent over that shown.

An alternative to the simple pneumatic test is shown in Fig. 10-18. Deviation from cryogenic temperature still results, however; but, turning the tank upside down and filling it with a low fluid density liquid to the level shown will result in an ambient temperature proof test of the tank without compromising the tank membrane thickness required for the true environment.

Table 10-3

14-Foot DIA LH_2 Droptank

Thickness Requirements for Room Temperature Proof Test

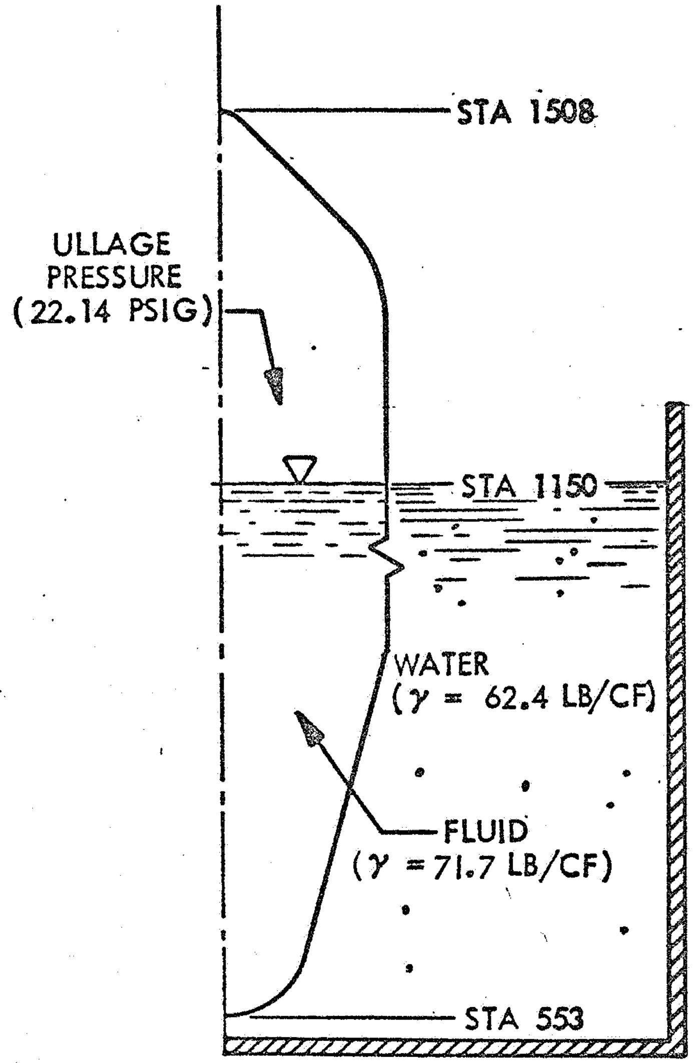


THICKNESS (IN.)	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}
2219-T-87 PROOF PRESS. @ RT WT = 2282 *	.025	.030	.033	.054	.052	.052	.052	.052	.026	.026	.052	.025	.025
301 CRES EXTRA HARD PROOF PRESS. @ RT WT = 1874 LB *	.010	.010	.010	.015	.015	.015	.015	.015	.010	.010	.015	.010	.010

*PNEUMATIC TEST

14-FOOT DIAMETER TANK (BASELINE)

HYDRO-PNEUMATIC PROOF TEST



MATERIAL: 2219-T81 ALUMINUM ALLOY

F_{t_u} = 62 KSI, MAX. $\sigma_{PROOF} = (62)\left(\frac{1.05}{1.40}\right) = 46.5$ KSI

EQUIVALENT $\Delta P_{REQUIRED}$ = 2.2 PSIG (CYLINDER SECTION)

REQUIRED FLUID DENSITY = 71.7 LB/FT^3

ADVANTAGES

- TEST MAY BE CONDUCTED AT ROOM TEMPERATURE
- CRITICAL SECTIONS ARE PROOF-TESTED TO ALMOST MAX. σ_{PROOF}
- NO SIGNIFICANT WEIGHT INCREASE WHEN COMPARED WITH TANK DESIGNED FOR FLIGHT CONDITIONS
- REQUIRES SIMPLE TEST STAND (TANK MAY BE SUSPENDED FROM HARD POINT AT STA 1508)

DISADVANTAGES

- DIFFICULTY OF FORMULATING FLUID DENSITY
- TANK NEEDS EXTENSIVE REMOVAL OF FLUID TRACES AFTER PROOF TEST
- TANK NOT PROOFED AT CRYOGENIC TEMPERATURES

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Fig. 10-18

Fig. 10-18

Further development of material characterization must be achieved in order to determine if testing at room temperature will compromise reliability at cryogenic temperatures. Some fracture mechanics investigations indicate that such a test deviation may be permitted. (See Section 10.5 for Droptank Acceptance Test Trade Study.)

10.4.2 Ullage Pressure Considerations

Subsequent discussion in Section 12 (Propulsion System) will point to the uncertainty of the optimum ullage pressure. Establishing a design ullage pressure profile is beyond the scope of this study, but a knowledge of the impact of ullage pressure on tank weight would aid in establishing the optimum pressure profile.

An analysis was performed for a range of ullage pressures from 25 psi to 33 psi, using the 2219-T81 aluminum baseline tank configuration. Two considerations were made: first, to vary the ullage pressure while the tank is full, venting down to 25 psia at burnout, and second, to hold the ullage pressure constant. Using 25 psia as the baseline value, Fig. 10-19 shows the weight penalty associated with both considerations. These weight values are for one tank, and represent the theoretical weight change. The true weight panelties are approximately 25 to 35 percent higher. No conclusions can be drawn from this figure until a study of the pressurization system is made, and the overall cost effectiveness is studied.

10.4.3 Ground Handling Considerations

General aerospace philosophy assumes that ground handling load environments should not dictate flight hardware strength requirements. Handling the empty droptank in the horizontal or vertical position, however, will require internal pressurization to prevent the tank from collapsing under its own weight. Pressurization requirements are a function of the tank weight. This weight varies during various stages of assembly between two extreme conditions: tank shell weight to full tank weight which includes insulation, plumbing, and shroud. The stored condition was also considered. If certain values of

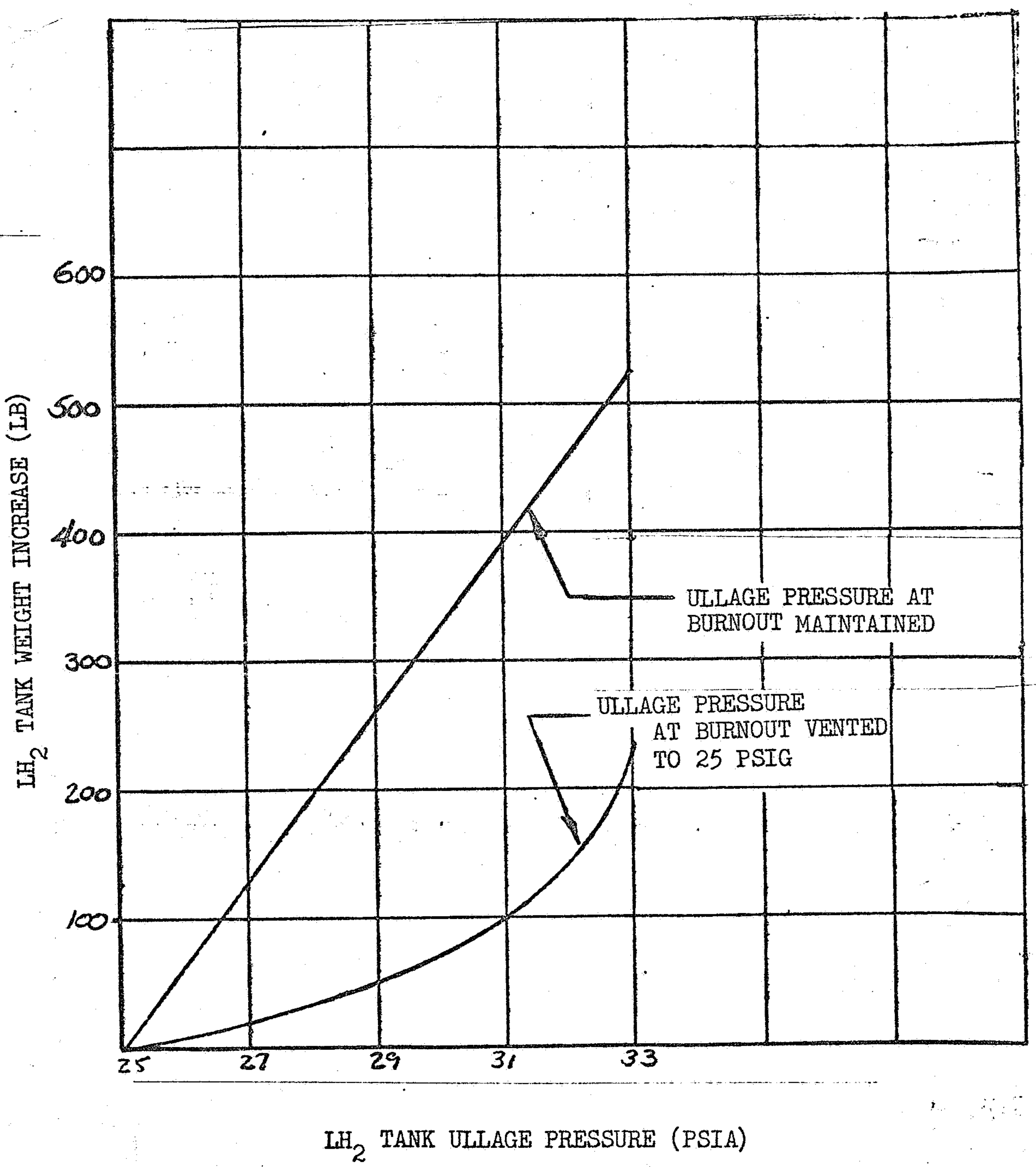


Fig. 10-19 Ullage Pressure Weight Penalty

internal pressure are maintained, handling can be achieved without compromising the flight weight. If, however, handling is required without internal pressurization, weight penalties up to 1,330 lb arise. The results of this study are summarized in Table 10-4. Note that the maximum internal pressure required is 2 psig. Internal pressurization has other advantages besides handling. Once the tank is cleaned and prepared for receiving LH_2 propellant, internal pressurization will help to insure total cleanliness. Secondly, an unpressurized tank could inadvertently collapse during a sudden change in temperature.

The details of the above analysis are presented in EM L2-12-01-M1-13, in the appendix to this report. (See Section 10.6 for the Droptank Ground Handling Trade Study.)

References

1. David Bushnell: Stress, Stability and Vibration of Complex Shells of Revolution: Analysis and User's Manual for BOSOR3, SAMSO TR-69-375 69 Sep 06.

2. B. O. Almroth, A. B. Burns, E. V. Pittner: Design Criteria for Axially Loaded Cylindrical Shells, J. Spacecraft, Vol. 7, No. 6, June 1970, pp. 714-720.

Table 10-4

Ground Handling Considerations

HANDLING CONDITION (2g DYNAMIC AMPLIFICATION)	PRESSURE REQUIRED (psig)	MEMBRANE WEIGHT PENALTY (LBS)	SYSTEM WT. PENALTY (LBS)*
HORIZONTALLY STORED	1.50	0	0
	0	355	890
HORIZONTALLY TRANSPORTED TO PAD ON ORBITER	2.0	0	0
	0	533	1330
VERTICALLY STORED	0.25	0	0
	0	132	330

* TWO TANKS, ASSUMING 1.25 NOF

10.5 DROPTANK ACCEPTANCE TEST TRADE STUDY

Tank acceptance tests normally consist of a proof pressure test predicated upon the worst-case operating condition. For this tank application, the worst-case operating conditions arise not from externally applied tank loads but purely from internal pressure, and as the strength of the tank material is greater at lower temperatures, the critical operating conditions occur when the last of the cryogenic hydrogen flows out. This described condition optimizes tank design with a varying wall thickness – heavy at the top where it is warmest (-100°F), and thinnest at the bottom where it is coldest (-420°F). (See Section 10.2 for more details.)

This tank design (varying wall thickness) produces a dilemma for proof pressure acceptance testing; and four different methods of accomplishing this test were investigated. Figure 10-20 shows a pictorial representation of these methods. They consisted of: (1) over-designing the tank (constant wall thickness) so it can be proof tested at ambient temperature, but causing a tank weight penalty; (2) inverting the tank, filling it to a predetermined depth with a low density liquid and pneumostatically testing it at ambient temperature to approximate the operational design stress conditions (see Section 10.4 for more detail on this test method); (3) filling the tank with liquid hydrogen and then draining the tank under constant ullage pressure to duplicate the actual operational condition; and (4) developing a technique of tank failure prediction using partial proof pressures and an acoustic emission inspection process which detects unacceptable tank flaws. This acoustic emission testing process is now in the laboratory experimental stage but was evaluated under the assumption that adequate development funds would accelerate it to a qualified process.

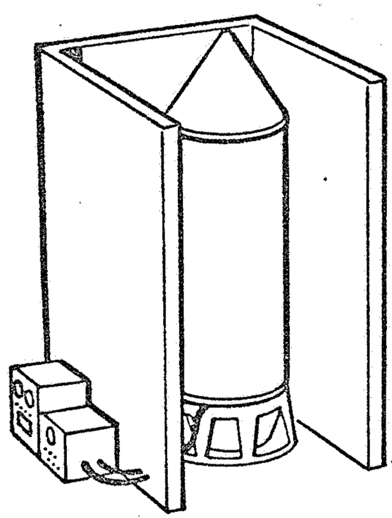
Table 10-5 presents the results of this tradeoff analysis between the four test methods described. Method (2) (the ambient hydropneumatic test) shows the greatest saving ($7 million) over the present standard test Method (1).

ACCEPTANCE TEST CONCEPTS

HEAVYWEIGHT TANK

+ 600 LB
PRESENT PRACTICE PROOF

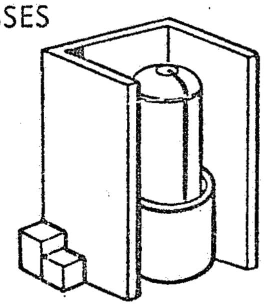
- TANK DESIGNED FOR AMBIENT TEMP PROOF TEST
- USES PRESENT CRYOGENIC TANK TEST PROCEDURES



LIGHTWEIGHT TANK

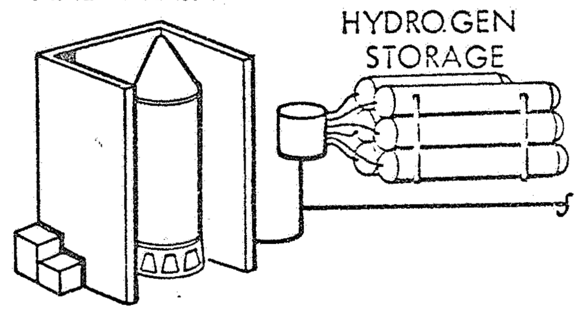
AMBIENT TEMPERATURE PROOF

- USED HYDROPNEUMOSTAT TO SIMULATE OPERATIONAL STRESSES



CRYOGENIC TEMPERATURE PROOF

- USES LH_2 FILL, SOAK, AND DRAIN



FAILURE PREDICTION PROOF

- USES ACOUSTIC EMISSION PROOF TEST
- ALLOWS AMBIENT TEMP/LOWER PRESSURE TESTING

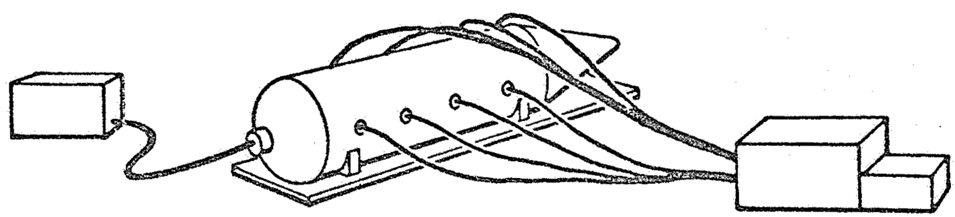


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Fig. 10-20

Fig. 10-20

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DROPTANK ACCEPTANCE TEST TRADEOFF STUDY

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	TEST CONCEPTS (WELD-BONDED ALUMINUM TANKS)			
	HEAVY WEIGHT TANK	LIGHTWEIGHT TANK		
	AMBIENT PNEUMOSTAT	AMBIENT HYDRO-PNEUMOSTAT	CRYO-TEMP PNEUMOSTAT	AMBIENT FAILURE PREDICTION
* BASIC TANK WEIGHT	(6040 LB) $ 9.3	(4880 LB) REF WT	(4880 LB) REF WT	(4880 LB) REF WT
TEST FACILITIES AND EQUIPMENT	$ 0.5	$ 1	$ 4	$ 0.7
TEST DEVELOPMENT	$ 0	$ 0.2	$ 0.4	$ 4
TEST MANPOWER	$ 6.6	$ 8.1	$10.5	$ 7.2
COMPARISON TOTAL	$16.4	$ 9.3	$14.9	$ 11.9
RELATIVE COST	REF	$-7.1	$-1.5	$-4.5

* DROPTANK WEIGHT SENSITIVITY = $8,000/LB

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Table 10-5

Table 10-5

The liquid hydrogen test method (3) shows the least saving with the acoustic emission test method (4) in the middle. The most signficant cost savings are associated with the lighter weight tank design; and while the lower combined facility, manpower, and development cost of method (2) makes it more attractive than the acoustic emission method (4) because of the $4 million development cost, it is worthwhile to note that if and when this method (4) is developed, it could then be phased into the droptank acceptance testing cycle with a possible additional saving to the remaining program.

10.6 DROPTANK GROUND HANDLING TRADE STUDY

Droptanks designed for the worst flight operating environment produce a tank which must be either pressure stabilized, stretched, or both to be handled empty on the ground. The only alternative to this method which uses auxiliary ground support systems (pressurization and special strongback fixtures) is to make the tank strong enough to support its own weight. This strengthening results in a tank weight increase. Table 10-4 of Section 10.4.3 shows the tank weight penalties associated with various unpressurized handling attitudes and conditions. A tradeoff study was made by using the conditions and weight values of Table 10-4 and comparing these with a pressure-stabilized tank concept. The results of this tradeoff are shown in Table 10-6. The pressure-stabilized tank handling concept was found to be slightly more cost-effective than the heavier weight free-standing tank stored vertically concept. This trade study showed basically that the cost penalty for heavier tanks was greater than the saving made by eliminating the more complicated and costly pressure-stabilizing handling equipment.

During this study, it was recognized that there is a compound effect associated with a heavier ground-system-designed tank versus a lighter flight-operation-designed tank. This compound effect is the sum of the advantages of a free-standing tank (less handling equipment required) and of a simple ambient temperature proof test (lower cost acceptance testing). A cursory tradeoff

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TANK GROUND HANDLING TRADEOFF STUDY

(COST IN $MILLIONS)

FOR AN ALUMINUM WELD-BONDED TANK

MAJOR COST PARAMETERS	PRESSURE-STABILIZED TANK	FREE-STANDING TANK		
		HORIZONTALLY STORED	VERTICALLY STORED	HORIZONTAL TRANSFER ON ORBITER
*TANK WEIGHT	(4,880 LB) REF WT	(5,770 LB) $ 7.1	(5,210 LB) $ 2.6	(6,210 LB) $ 10.7
HANDLING EQUIPMENT COST	$ 8.8	$ 6.9	$ 5.7	$ 5.7
**OTHER TANK COSTS	$200.4	$202.5	$201.4	$208.3
COMPARISON TOTAL	$209.2	$216.5	$209.7	$224.7
RELATIVE COST	REF	$+ 7.3	$ +0.5	$ +15.5

D03898

*DROPTANK WEIGHT SENSITIVITY = $8,000/LB
**USING LMSC CER

Table 10-6

Table 10-6

study, taking into account both of these advantages of the heavier tank versus the cost of the weight penalty, still showed the lighter weight tank design slightly more cost-effective. However, as these tradeoff studies are not refined at this time, it should be recognized that a more complete trade study of lightweight versus heavyweight tanks should be undertaken when more detailed design and costs are available.

Although the system evaluation consists of feasibility and cost as well as weight, the main emphasis has been placed on weight. Comments concerning feasibility are made, but an overall determination of feasibility must be established by a test program.

11.1 CANDIDATE TPS CONCEPTS

The TPS concepts that were investigated are shown in Fig. 11-1. One ascent and four ascent/entry concepts are shown. An additional ascent/entry concept was considered initially but is not shown because of insufficient data upon which to base an analysis. This concept is foam insulation only with no protective ablator. Data are not available on the material performance under the heating/erosion rates experienced by the system during entry. Assuming an erosion rate similar to that for ascent, the required foam thickness would exceed 4 in. for an intact entry. The spray-on application would be complicated since thicknesses this great cannot be applied in a single application. This system possibly could be modified to be more suitable for entry application. However, because of uncertainties concerning its performance, it is not included in the concept analysis at this time.

11.1.1 Ascent Concepts

One ascent TPS concept consists of SOFI* applied externally on the tank wall. In the interference heating region, an ablator is applied to the foam to provide protection from the increased heat rates.

Another possible ascent concept places the ablator directly on the tank wall exterior in the interference heating region. The SOFI is then applied over the entire outer surface including the ablator. This concept was not analyzed in detail due to time limitations.

* Sprayed On Foam Insulation

TPS CONCEPTS	TANK: INITIAL TEMPERATURE (°F)	TANK: MAXIMUM TEMPERATURE (°F)	INSULATION: REQUIRED FOR ENTRY	INSULATION: MAXIMUM TEMPERATURE (°F)	ABLATOR: MAXIMUM BONDLINE TEMPERATURE (°F
ASCENT CONCEPT					
NONINTERFERENCE REGION: INSULATION	-423	<200	-	200	-
INTERFERENCE REGION: ABLATOR / INSULATION	-423	<200	-	200	200
ENTRY CONCEPTS					
1 A/E: ABLATOR / INSULATION	-423	200	YES	200	200
2 A/E: INSULATION / ABLATOR	-423	500	NO	-	500
3 A/E: ABLATOR / INSULATION	>-423	500	NO	500	500
4 A/E: ABLATOR	-423	500	NO	-	500

D03628(1)

Fig. 11-1 Candidate TPS Concepts

11.1.2 Ascent/Entry Concepts

In Concept 1 A/E, the entire tank outer surface is covered with SOFI. An ablator is then applied over the foam to provide entry protection. In Concept 2 A/E, the ablator is applied directly to the tank wall exterior and then covered with SOFI. It may not be necessary to machine the foam outer surface in this system. If not, the system cost will be reduced significantly. Concept 3 A/E employs an internal insulation system which could be either a sealed foam system similar to that used on the S-IVB, or a vapor barrier system similar to that being investigated by Martin and Convair. However, these insulations have a higher density than SOFI and require a greater thickness to achieve the same thermal resistance because of higher thermal conductivities. In addition, the tank weight increases because of the volume increase and greater membrane thicknesses due to higher temperature allowables. Concept 4 A/E consists of an ablator applied directly to the tank wall exterior with no other insulation.

11.2 CANDIDATE TPS MATERIALS

The candidate materials considered are shown in Table 11-1. The cryogenic insulation material may be either internal or external to the tank wall. Internal insulation could be either a sealed foam similar to that used on the S-IVB or a vapor barrier system. The S-IVB system is basically a glass fiber reinforced foam bonded to the tank wall in panels with Lefkoweld 109/LM52. Normco 7343/7139 resin is used to laminate 116 glass cloth to the foam. The resin acts as an adhesive and sealer.

The internal vapor barrier system could be a plastic honeycomb or possibly an open cell foam. The ρk of this system, and therefore the weight for an equivalent thermal resistance, is about 4/3 that of the S-IVB system.

Table 11-1

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CANDIDATE MATERIALS

INSULATION

- INTERNAL
  - GLASS FIBER REINFORCED FOAM (S-IVB)
  - INTERNAL GAS BARRIER SYSTEM
- EXTERNAL
  - SOFI (S-II)

ABLATOR

- CORK
- PHENOLIC NYLON (FILLED WITH PHENOLIC MICRO-BALLOONS)
- SILICON (TBS-757A)
- PURPLE BLEND (NASA/LANGLEY SILICON ABLATOR)

D03580

Table 11-1

The external spray-on foam insulation (SOFI) is Nopco BX-250A polyurethane foam similiar to that used on the S-II. The foam exterior surface is sealed with three coats of Chemseal 3547 polyurethane and a white vinyl topcoat of Dynathern V455. Discussion with NAR and MSFC personnel has led to the conclusion that perhaps the coating should be more porous to relieve the divoting problem observed during detanking operations. Therefore, the current study assumes one coat of Chemseal 3547 and one coat of Dynathern V455. The ρk of this system is about 1/6 that of the internal S-IVB system.

A list of the ablators that were considered is shown in Table 11-1. Moderate density ablators were considered because they appear to be the best selection considering weight, surface recession and development status.* Lower density ablators would probably require a honeycomb matrix to insure char retention.

11.3 THERMAL ANALYSIS

Thermal analysis of the GAC two-and-one-half-stage droptanks was performed in two phases. The first phase was concerned with the ascent TPS requirements and interference heating effects on the orbiter and droptanks. The second phase centered around the entry environment and TPS required to provide for intact droptank impact.

Ascent TPS requirements and thermal environment were found to be generally comparable to the available GAC data covering this area (see EM L2-12-01-M1-7, in Appendix).

Ascent heating predictions were based on Spalding-Chi heating theory with a transition Reynolds number of 100,000 based on boundary layer length. This

*Graham, John W., Mosher, David A., and Victer, Ira: Ablative Leading-Edge Design Concepts for the Shuttle Orbiter, NASA TMX-2273, 1971.

relatively low transition Reynolds number was assumed to account for the flow-disturbing effects of the orbiter shock system. Ascent heating histories were calculated for three locations based on radiation equilibrium wall temperatures.

Comparison of GAC-predicted tank heating rates with test data indicates reasonable agreement between these assumed and measured interference factors. Factors above 10 are indicated on the conical section. On the cylindrical section, factors close to 6 for the forward part and near 3 for the aft portion are indicated. These factors also show reasonable agreement with the test data. The local undisturbed heat transfer coefficient ratio is appropriate for areas on the droptank where there is no interference heating. The value at which the ablator analysis was performed is the ablator evaluation interference factor at $h_{LOCAL}/h_{1\ Ft\ SPHERE} = 0.19$.

The spray-on foam insulation (SOFI) on the droptank outer surface over the LH_2 tank is assumed to erode at a rate of 2.5 mils/sec after the surface temperature exceeds 200°F. Information to substantiate this assumption was found in a report on SOFI characteristics.* Erosion data were obtained from two flights of the X-15 on which SOFI was applied to the drag brakes of the research aircraft. The test flight envelope approximated the S-II ascent heating environment. Motion pictures and thermocouple temperature histories of the speed-brakes during flight were taken and later analyzed. Erosion rates of about 2.5 mils/sec were indicated by the test data during periods of significant heating ($T_{surface}$ >200°F). Effects of foam roughness inherent in the spray application were analyzed (see EM L2-12-01-M1-8) and found not to create any significant heating increase.

The second phase of the GAC thermal analysis was done to outline the TPS requirements to provide for intact droptank impact (see EM L2-12-01-M1-10 in Appendix). The first droptank entry mode studied assumed the tanks to be

*NR letter 69MA5502 to W.F. LaHatte from W.F. Ezell, Subject: Contract NAS 7-200, Spray Foam Insulation Test X-15, Final Report, dated 10 June 1969 tumbling throughout reentry, thereby exposing the entire tank outer surface to approximately the same thermal environment. Later analysis on the droptanks shows that the tanks tended to stabilize rather than continue tumbling as previously assumed. The lower TPS weight associated with smaller trim angles shows the advantage of adding some sort of stabilization means to the droptanks. The reduction in TPS weight required to provide for intact droptank impact would be significant.

11.4 EVALUATION OF TPS CONCEPTS

11.4.1 Ascent Concept

The ascent TPS ablator thickness requirements are shown in Fig. 11-2. All ascent insulation sizing assumed the surface to be at $0^{\circ}F$ at liftoff with a linear gradient through the insulation to a structure temperature of $-420^{\circ}F$, the LH_2 temperature. Limiting the maximum foam/cork interface temperature to $200^{\circ}F$ requires about 0.25 in. of cork over the SOFI. The magnesium nose cap requires approximately 0.15 in. of cork to limit the maximum magnesium temperature to $300^{\circ}F$.

The influence of assumed interference heat transfer coefficient is shown in Fig. 11-3. The ratio of the local to a 1-ft radius sphere stagnation point heat transfer coefficient is shown as a function of cork thickness and weight. Heat transfer coefficients ratios of 0.19 and 0.30 were used for the laminar and turbulent flow portions, respectively, of the ascent flight when calculating insulation thicknesses.

The ascent TPS system weights are summarized in Table 11-2. The system weights include 0.75-in. thick SOFI, ablator, outer coating, and bond (in the case of cork). It was assumed that the drain lines, recirculation lines, and pressurization lines were insulated with SOFI and all external lines and

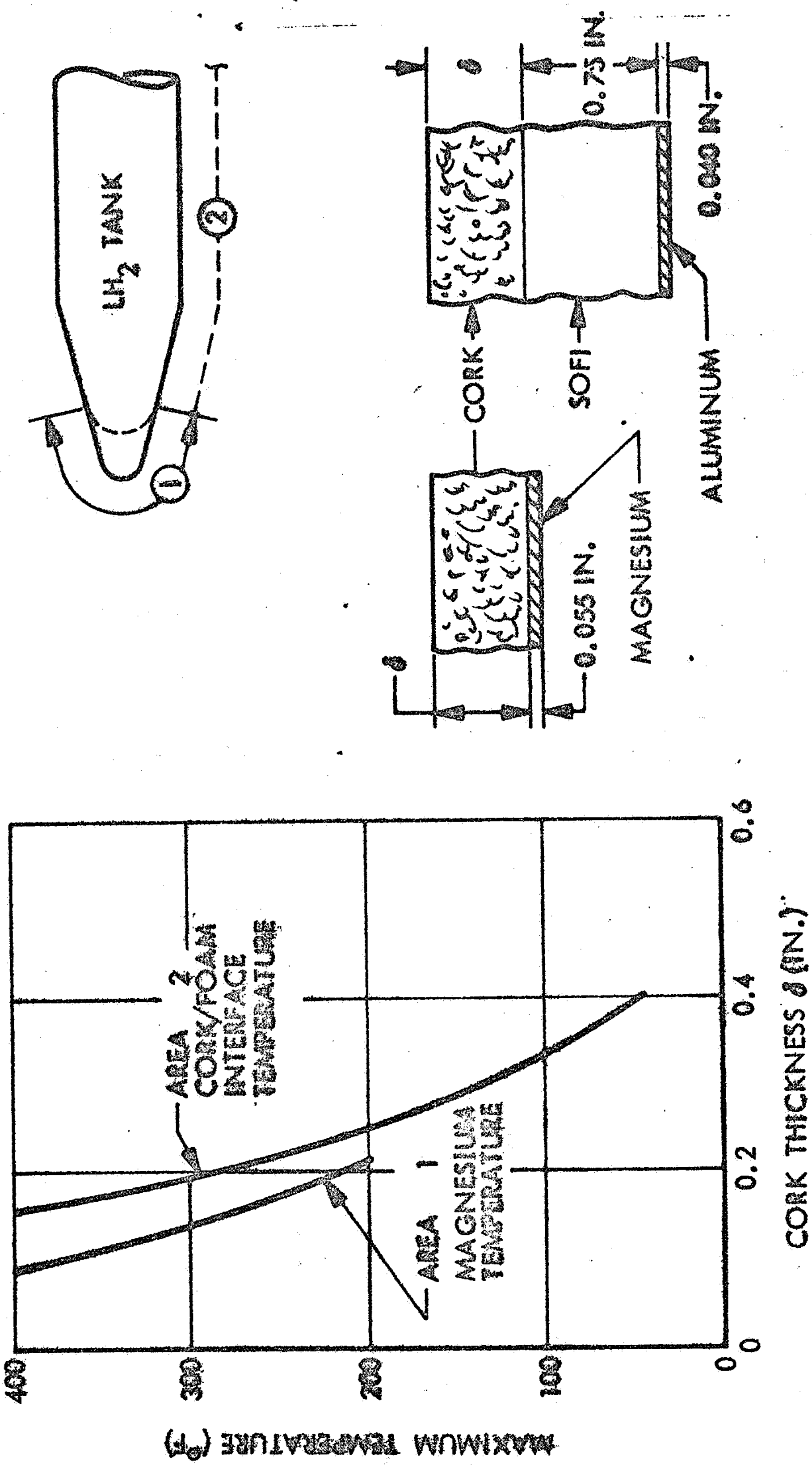

Fig. 11-2 Ascent TPS Requirements, System 1

Fig. 11-2

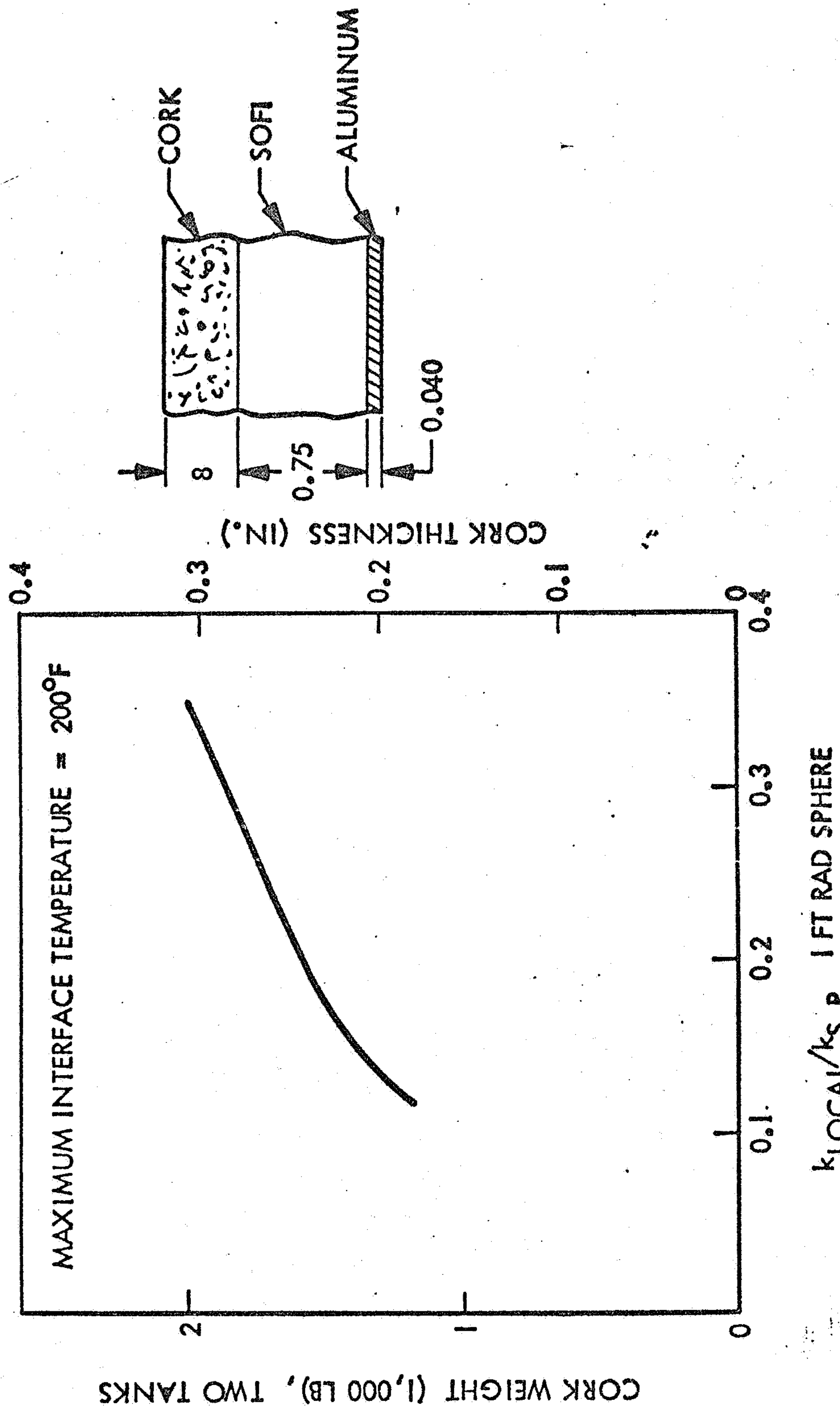

Fig. 11-3 Effect of Interference Heat Transfer Coefficients on Ascent TPS Requirements, System 1

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Fig. 11-3

Table 11-2

ACENT TPS WEIGHTS

ABLATOR DESCRIPTION	DENSITY (PCF)	SYSTEM WEIGHT* (LB)
Cork (Armstrong 2755)	30	3,403
Phenolic Nylon (Filled with Phenolic Micro-Balloons)	34.5	4,159
TBS-757A (Silicon Ablator - LMSC Modified RTV-757)	32	3,945
Purple Blend (NASA/Langley Silicon Ablator)	41	4,705

*Includes 0.75 in. thick SOFI ($\rho = 2.0$ lb/ft^3), bond and coating weights. Does not include 102 lb TPS weight for jettisonable forward cones.

Table 11-2

supports were covered with ablator. The cork ablator system is lightest in weight, with TBS-757A silicon ablator next lightest.

Analysis indicates that the TPS could be lightened by putting the ablator on the outer tank wall with the foam over it. However, the heat rate into the tanks would be greater and additional analysis would be required to determine the impact on tank pressurization and liquid residuals.

Based on the weight comparison, cork was chosen for the baseline ascent TPS shown in Fig. 11-4.

11.4.2 Ascent/Entry Concepts

The ascent/entry TPS systems were sized to provide intact impact for a tumbling entry mode. Ascent/entry insulation sizing assumed the surface initial temperature to be 200°F at droptank separation with a linear gradient through the insulation to the structure start temperature, generally -100°F unless noted. The weight penalty associated with the intact entry is shown in Fig. 11-5 for Concept 1 A/E - System 1. The curve shows the altitude at which the foam/cork interface reaches the design limit of 200°F. The cork weight penalty associated with intact impact compared with reaching the design limit at 400,000-ft altitude is over 5000 lb.

Similar curves are shown in Fig. 11-6 for Concept 2 A/E - System 1 which is also representative of Concept 3 A/E if the internal tank insulation is neglected. Tank temperatures of 400°F and 600°F are shown along with the baseline design tank temperature limit of 500°F. More than 1000 lb of weight could be eliminated if the temperature limit could be increased to 600°F. Intact impact with 500°F maximum tank temperature results in about a 3000-lb weight penalty. Weight penalty associated with initial tank temperature is shown in Fig. 11-7. The incremental weight associated with an initial tank temperature difference of 100°F from the -100°F baseline is about 600 lb.

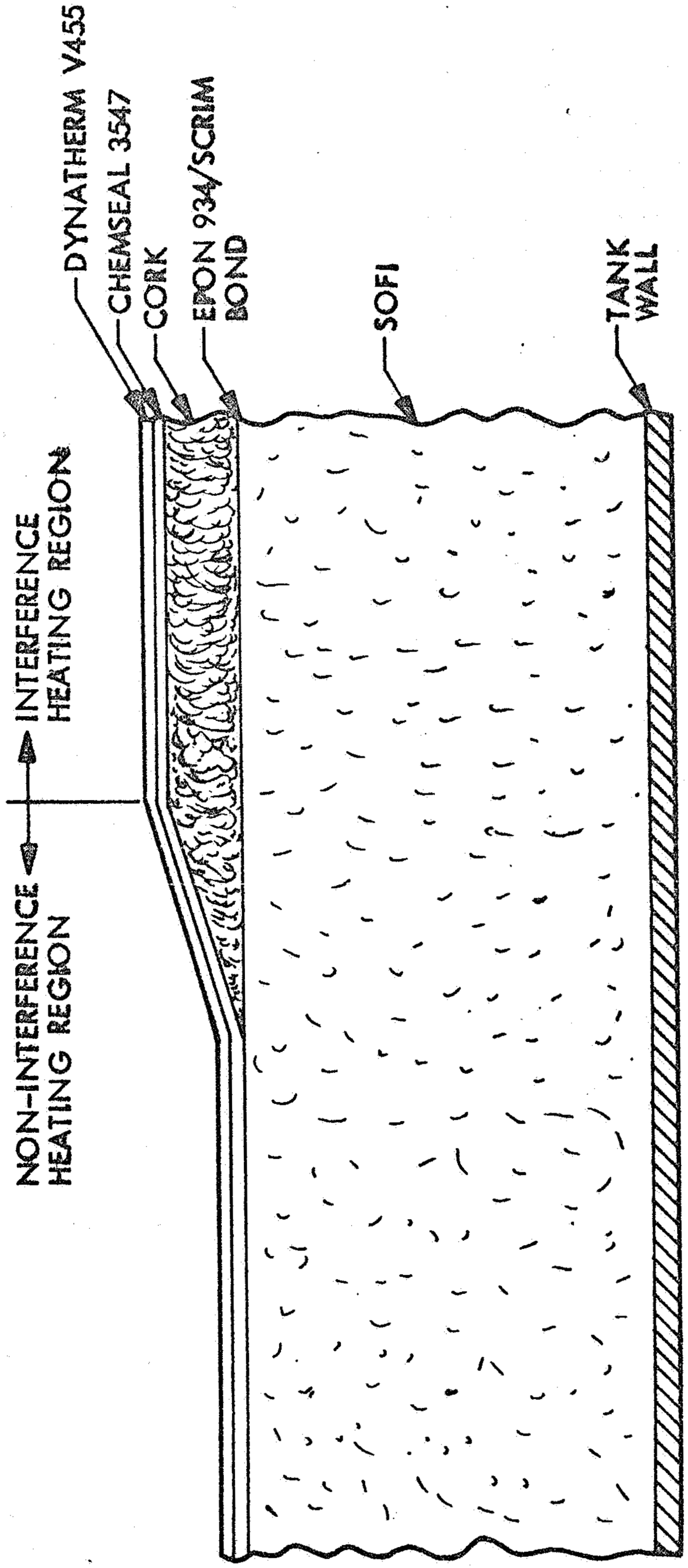


Fig. 11-4 Baseline Ascent TPS

Fig. 11-4

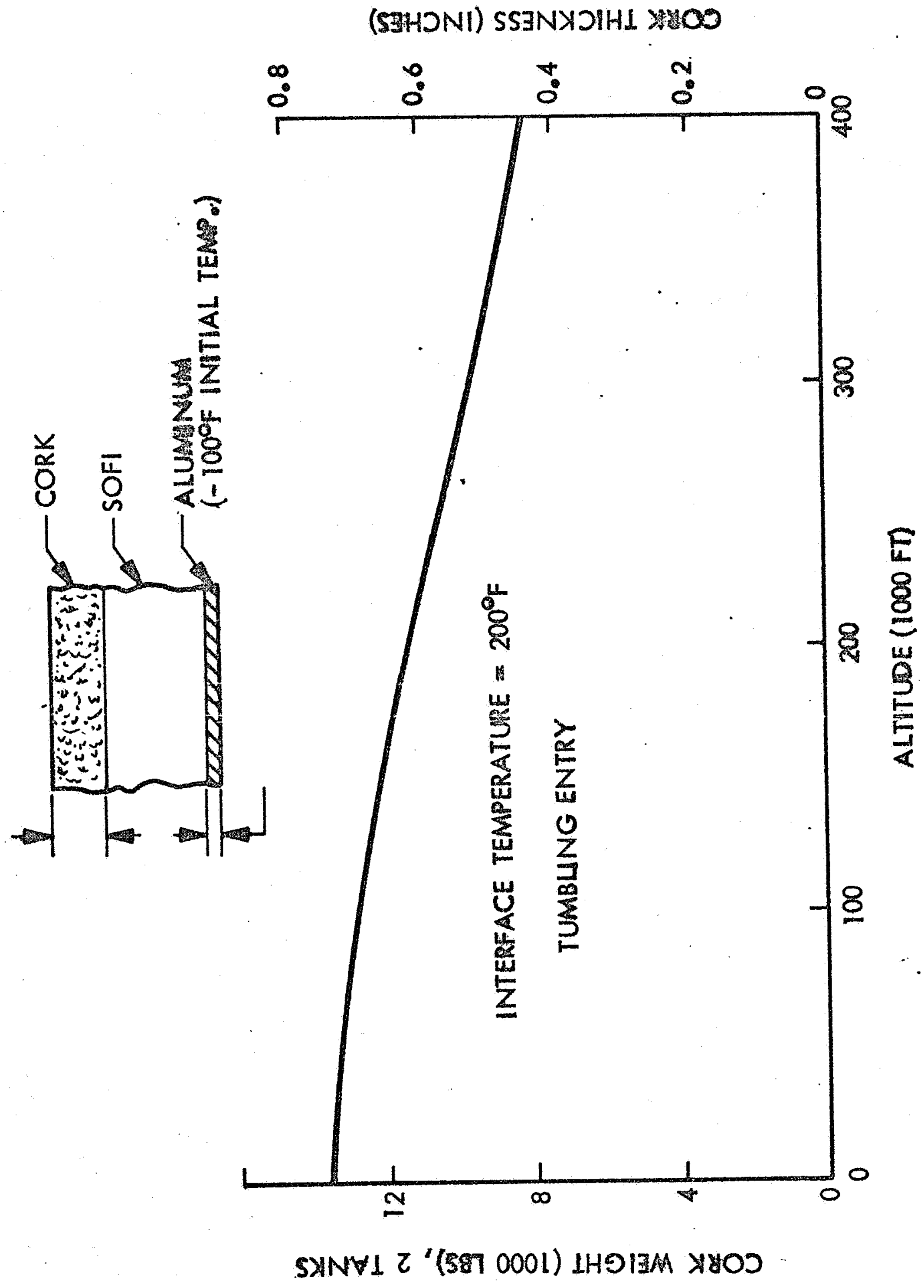


Fig. 11-5 Ascent/Entry TPS Requirements, Concept 1 A/E - System 1

Fig. 11-5

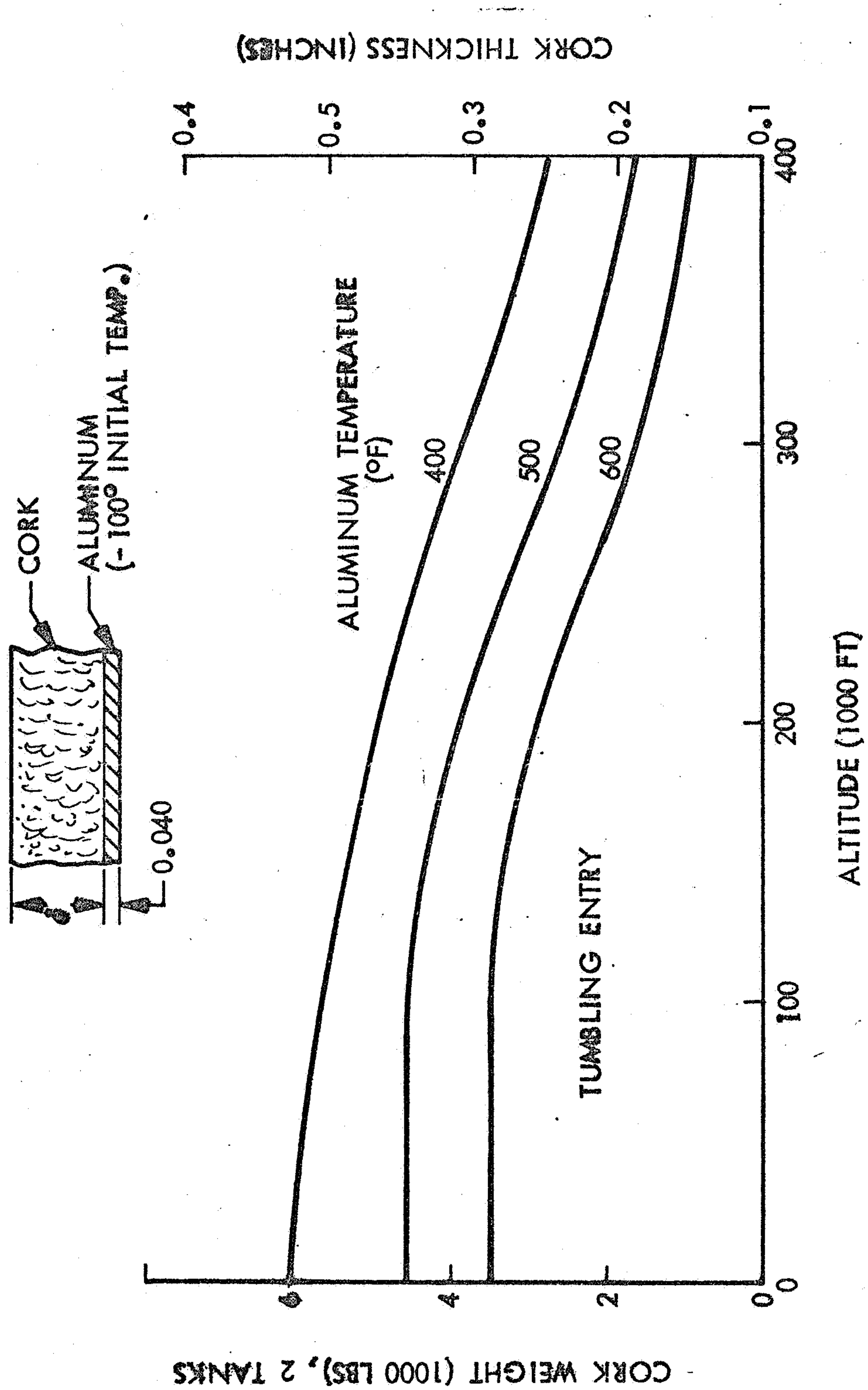


Fig. 11-6 Ascent/Entry TPS Requirements, Concept 2 A/E - System 1

Fig. 11-6

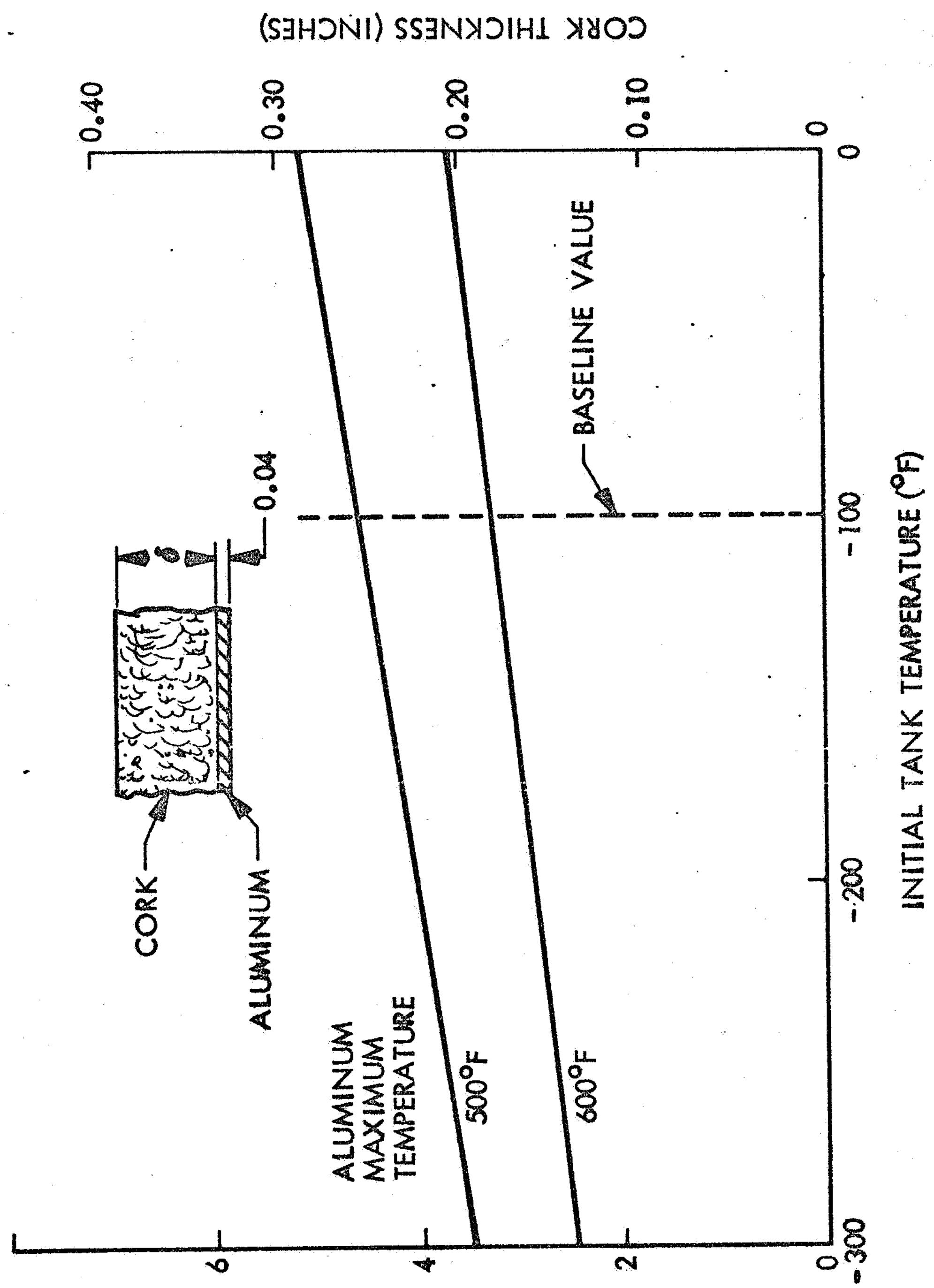


Figure 11-7 Effect of Initial Tank Temperature on TPS Weight, Concept 2 A/E - System 1

Fig. 11-7

The effects of stable entry compared to the baseline tumbling entry mode are shown in Fig. 11-8. At an angle-of-attack of 5 deg, the system weights are 2 to 3 percent greater than those for tumbling entry. At 25 deg angle-of-attack, the weights are about 50 to 60 percent greater than those for tumbling entry.

The system weights are shown in Fig. 11-9. Concept 2 A/E weights are lower than the other concept system weights. Use of cork for the ablator results in the lightest total system weight of any other system analyzed. System 1 A/E, which is similar in concept to the ascent TPS concept, is about twice the weight of Concept 2 A/E and about four times the weight of the ascent TPS system. System 2 A/E is selected as the baseline system on the basis of minimum weight. The system is shown in more detail in Fig. 11-10.

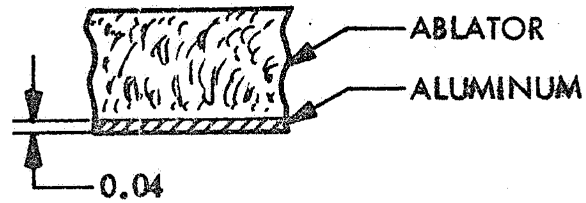
11.5 PROBLEM AREAS

Results of the TPS studies are summarized in Fig. 11-11. The selected baseline systems are shown with associated system weights and costs. Problem areas and further development requirements are noted.

Experience with cork applied to the foam outer surface on the S-II showed occasional cork debonding due to expansion of cryo-pumped air components during detanking operations. This problem may exist when other ablators are applied over the foam, although it would probably occur less due to lower porosity of the other ablators studied.

Systems that utilize an ablator next to the tank wall may have problems with material failures due to tank contraction and/or material embrittlement.

Foam or cork divoting may occur during detanking operations. Additional outer coating development is indicated.



ENTRY MODE	TUMBLING	STABLE, $\eta = 5^\circ$		STABLE, $\eta > 20^\circ$	
SYSTEM	SYSTEM WEIGHT (LBS)	SYSTEM WEIGHT (LBS)	Δ WEIGHT (LBS)	SYSTEM WEIGHT (LBS)	Δ WEIGHT (LBS)
CORK	6,408	6,557	149	9,533	3,125
NYLON PHENOLIC	7,747	7,977	230	12,407	4,660
TBS-757A	7,237	7,457	220	11,587	4,350
PURPLE BLEND	9,037	9,297	260	14,587	5,550

Fig. 11-8 Effect of Entry Mode on Ascent/Entry TPS Weight, Concept 2 A/E

Fig. 11-8

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ASCENT/ENTRY TPS CONCEPT EVALUATION

	TPS CONCEPT	ABLATOR	SYSTEM WEIGHT (LBS)
1 A/E	ABLATOR / INSULATION	CORK PHENOLIC NYLON TBS - 757A PURPLE BLEND	15,373* 21,157 19,687 24,987
2 A/E	INSULATION / ABLATOR	CORK PHENOLIC NYLON TBS - 757A PURPLE BLEND	6,408 7,747 7,237 9,037
3 A/E	ABLATOR / INSULATION	CORK PHENOLIC NYLON TBS - 757A PURPLE BLEND	10,638** 11,977 11,467 13,267
4 A/E	ABLATOR	CORK PHENOLIC NYLON TBS - 757A PURPLE BLEND	26,387*** 32,161 35,261 52,161

*INCLUDES 0.75 INCH SOFI (ρ = 2.0 LB/FT^3)
**INCLUDES 1.5 IN., 6.0 LB/FT^3 INTERNAL INSULATION, DOES NOT INCLUDE INCREASED TANK WEIGHT
***SIZED FOR GROUNDHOLD REQUIREMENTS

Fig. 11-9

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Fig. 11-9

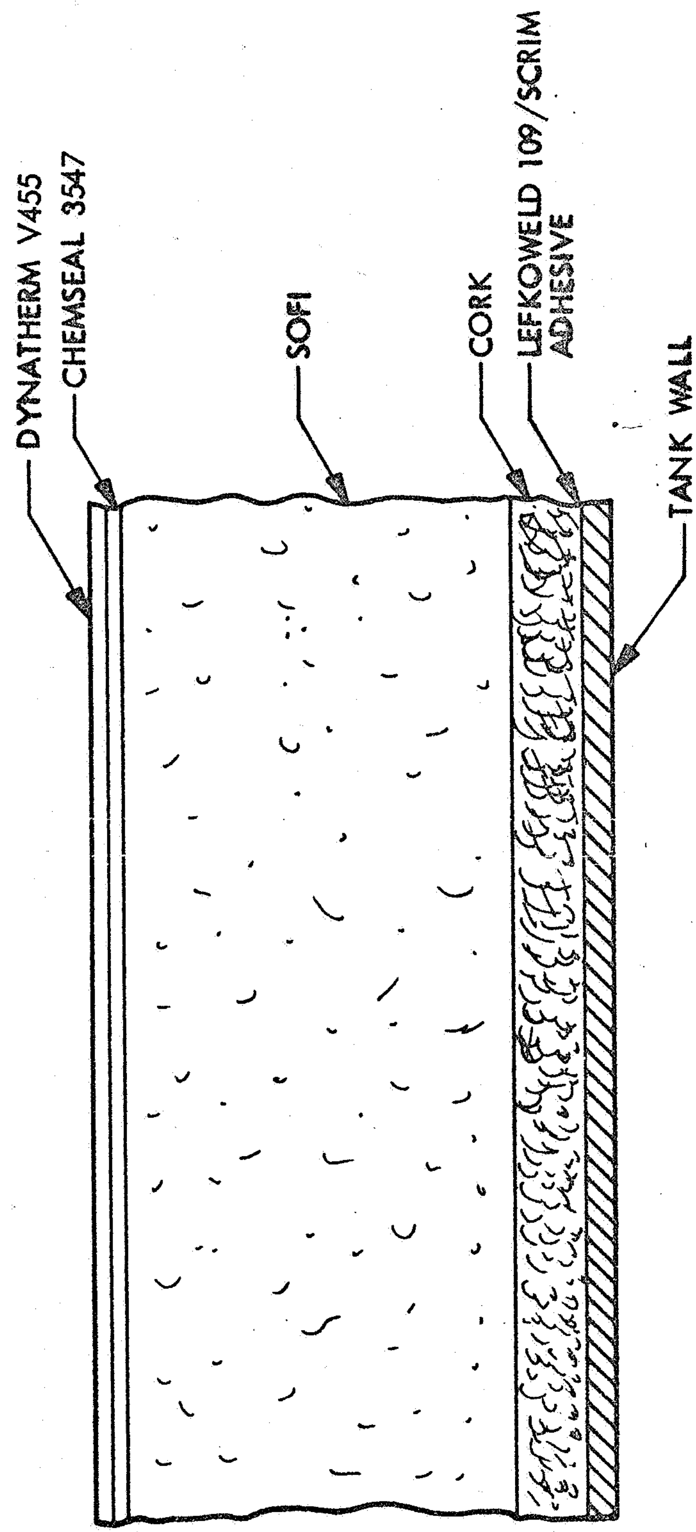
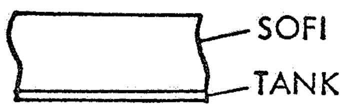
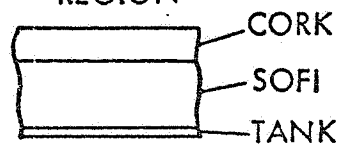
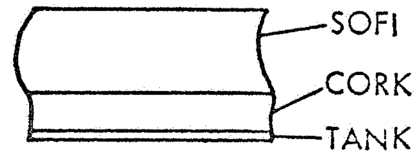


Fig. 11-10 Baseline Ascent/Entry TPS

Fig. 11-10

	ASCENT SYSTEM		ASCENT/ENTRY SYSTEM
	NONINTERFERENCE REGION 	INTERFERENCE REGION 	
TPS WEIGHT (LB), TWO TANKS	3,403		TUMBLING ENTRY, DEG 6,408 STABLE ENTRY (η = 5 DEG) 6,557 STABLE ENTRY (η>25 DEG) 9,533
PROGRAM COST DIFFERENTIAL*	REF		+ 50M (TUMBLING) + 75M (η > 25 DEG)
PROBLEM AREAS	PROBLEMS ASSOCIATED WITH CRYOPUMPING CORK/FOAM SEPARATION APPLYING PANELS TO CURVED SURFACES ABLATOR/BOND EMBRITTLEMENT (ASCENT/ENTRY SYSTEM)		
DEVELOPMENT AREAS	OPTIMIZE FOAM SPRAY TECHNIQUES TO OBTAIN CLOSER TOLERANCES DETERMINE MACHINING REQUIREMENTS OPTIMIZE VAPOR BARRIER SYSTEM OPTIMIZE ABLATOR DENSITY		

*SEE SYSTEM DESIGN EVALUATION SECTION

Fig. 11-11 Baseline TPS Summary

D03849

Application of cork panels to curved surfaces should be investigated. Preformed panels may be necessary in areas of low radius of curvature.

Ablators should be investigated to determine lowest usable density without the necessity of a honeycomb matrix for char reinforcement. The feasibility of the TPS concepts investigated require additional investigation, particularly testing. The system should be subjected to simulated environmental conditions to determine system integrity, reliability and thermal performance. Until further data are available, only weight and, to some extent cost, information can be used in rating the systems. This type of evaluation results in the baseline systems described.

11.6 INSULATION/TPS TRADE STUDIES

The five different TPS configurations, shown in Section 11.4 (Figs. 11-9 and 11-10), were evaluated in this tradeoff study to determine the most cost-effective TPS design and also to assess the penalty associated with providing tank reentry protection to limit dispersion. Table 11-3 presents the study results which indicate that the main cost driver is the TPS weight. The lowest cost design for ascent and reentry protection is one with the cork ablator bonded to the external tank wall and the foam sprayed over the top of the cork. This design provides the lowest weight. However, the manufacturing cost for this tank-cork-foam buildup method is slightly higher than for the tank-foam-cork buildup method, chiefly because the cracks between the aluminum weld-bonded panels must be filled prior to cork application.

The program cost penalty between the ascent only TPS system and the lowest cost ascent/reentry TPS system is approximately $50 million. This cost penalty of $50 million is for a TPS designed for rumbling entry, while the penalty for stable entry of the same TPS design is $75 million.

Table 11-3

DROPTANK TPS TRADEOFF STUDY (COST IN $MILLIONS)

MAJOR COST PARAMETERS	TPS CONFIGURATION: ASCENT TPS ONLY	ASCENT AND REENTRY TPS: TUMBLING				STABLE
	IA	1 A/E	2 A/E	3 A/E	4 A/E	2 A/E
* TANK TPS WEIGHT	(3,403 LB) REF WT	(15,373 LB) $ 96	(6,408 LB) $ 24	(10,638 LB) $ 78**	(26,387 LB) $ 184	(9,533 LB) $ 49
PRODUCTION COST	$ 62	$ 68	$ 88	$ 264	$ 64	$ 88
COMPARISON TOTAL	$ 62	$ 164	$ 112	$ 342	$ 248	$ 137
RELATIVE COST	REF	$ +102	$ +50	$ +280	$ +185	$+75

* DROPTANK WEIGHT SENSITIVITY = $8,000/LB
** TANK WEIGHT PENALTY NOT INCLUDED

D03833

Section 12
PROPULSION SYSTEMS

Design concepts for propulsion systems have been examined to support structural design, development, and production cost studies. These investigations involved consideration of propellant stratification, pressurization/venting modes, propellant recirculation for engine chilling, instrumentation, and provisions for separation of the droptank from the oribter. The aspect of one-time usage provides a strong incentive to minimize droptank fabrication costs in every component and assembly. Cost reductions at the expense of operational reliability, however, are not warranted. In the following sections, propulsion systems associated with the design and operation of the droptank during prelaunch and ascent phases are described together with the analyses that were conducted to confirm the viability of the subsystem. Propulsion system concepts which, if incorporated, will contribute to an intact reentry capability, are also presented. Retrorooket performance requirements, rocket motor availability and installation are presented in Section 5.

12.1 PRESSURIZATION/VENTING

The establishment of an ullage pressure time-history for the liquid hydrogen droptank constitutes one of the key criteria for its design. Accordingly, a thermodynamic analysis (see EM L2-12-02-M1-2 in Appendix) was performed to examine factors contributing to droptank pressure throughout prelaunch and ascent phases prior to orbit injection. An operating ullage pressure of 25 psia was selected as a target value to facilitate the conduct of a parallel analysis for droptank structural design as well as to confirm the value selected by Grumman for their preliminary design. This analysis took into account stratification of liquid hydrogen in the tank and variations in droptank wall heat flux induced by ascent heating and insulation thickness.

The liquid hydrogen thermal stratification profiles presented in Fig. 12-1 for 3/4 in. thick insulation is typical of variations in propellant temperature along the droptank centerline for insulation thicknesses from 3/8 in. to 1 1/8 in. as a function of time measured from liftoff. It was assumed that the ullage gas vent was closed 50 sec prior to liftoff and that vehicle acceleration and altitude profiles in Fig. 12-2 describe the trajectory conditions. The short term reduction in acceleration that occurs approximately 50 sec. after liftoff is due to attainment of a max. q level of 500 lb/ft^2. As discussed in Section 11, the foam-type insulation will progressively errode in areas where excessive scrubbing velocities occur and where interference heating increases the surface temperature of the foam above approximately 200°F. In these areas, equivalent to 30 percent of the tank surface, a layer of cork is bonded to the external surface of the foam insulation. Heat flux rates for these surfaces are depicted in Fig. 12-3 and were used in the propellant stratification analysis. From the ascent trajectory conditions and the fluid dynamic conditions within the bulk of the liquid hydrogen, the pressure-time history presented in Fig. 12-4 was constructed. This analysis also shows that with 3/4 in. insulation, venting is not required prior to booster-orbiter separation. As part of the orbiter stage rocket engine start sequence, prestart pressurant (gaseous hydrogen/helium) is injected into the droptank ullage to satisfy engine start NPSP requirements. Referring to Fig. 12-1, the LH_2 temperature at the tank discharge point is $\approx$ 37°R which is equivalent to a vapor pressure of 16 psia. If propellant inertial start pressure losses are less tha 0.5 psi, rocket engine NPSP requirements are 2 psi and valve pressure losses in the feedline are 3 psi (or less), then an ullage pressure of 5.5 above the 16 psia propellant vapor pressure is required to start the rocket engines. According to the propellant stratification analysis, this pressure (21.5 psia) will occur without prepressurization (see Fig. 12-4). Conservatively, prepressurization to 26 psia was used in the analysis. The pressure peak of 26 psia decayed to 25 psia in less than 30 sec and remained below this pressure level throughout

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LIQUID TEMPERATURE PROFILES

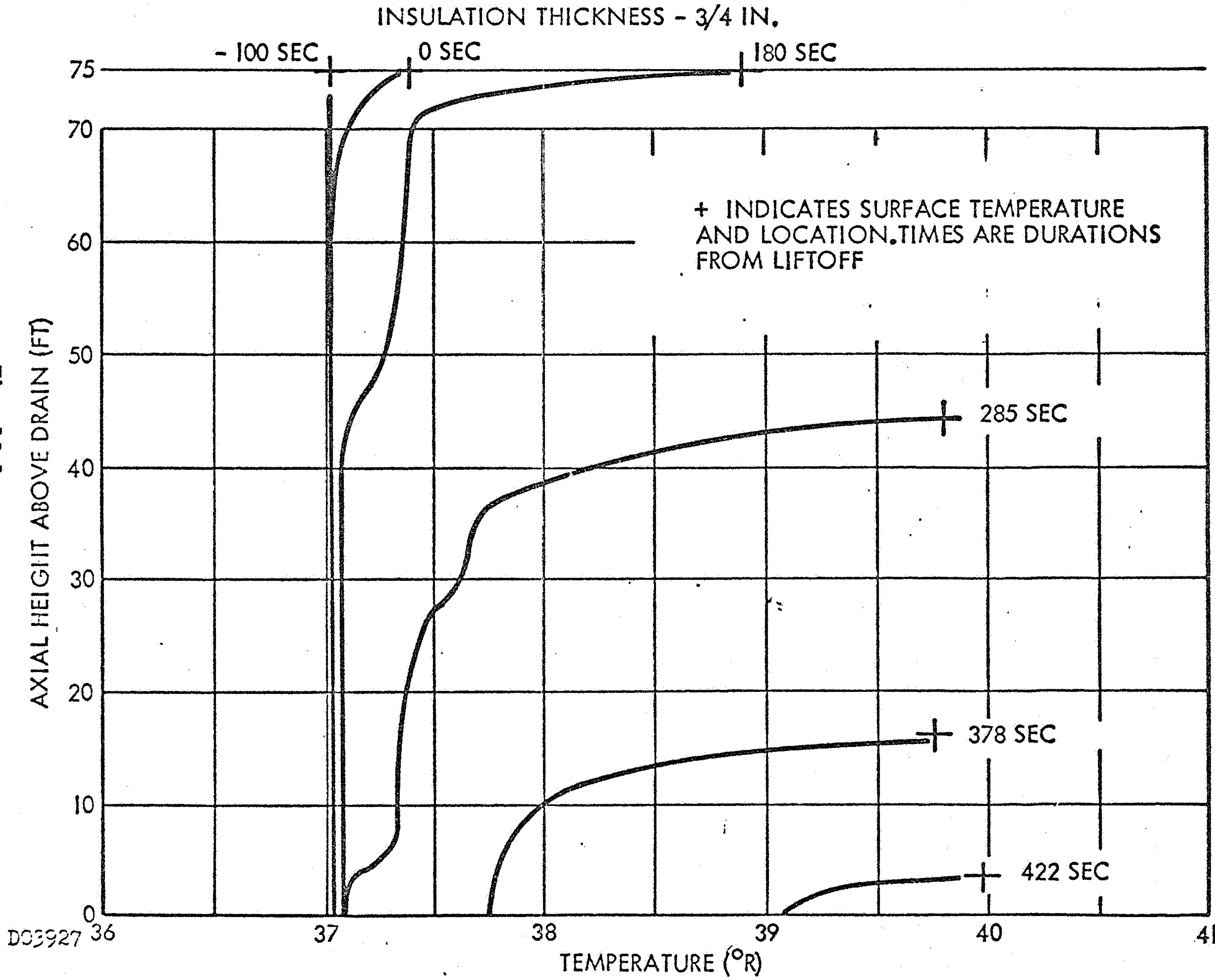


Fig. 12-1

Fig. 12-1

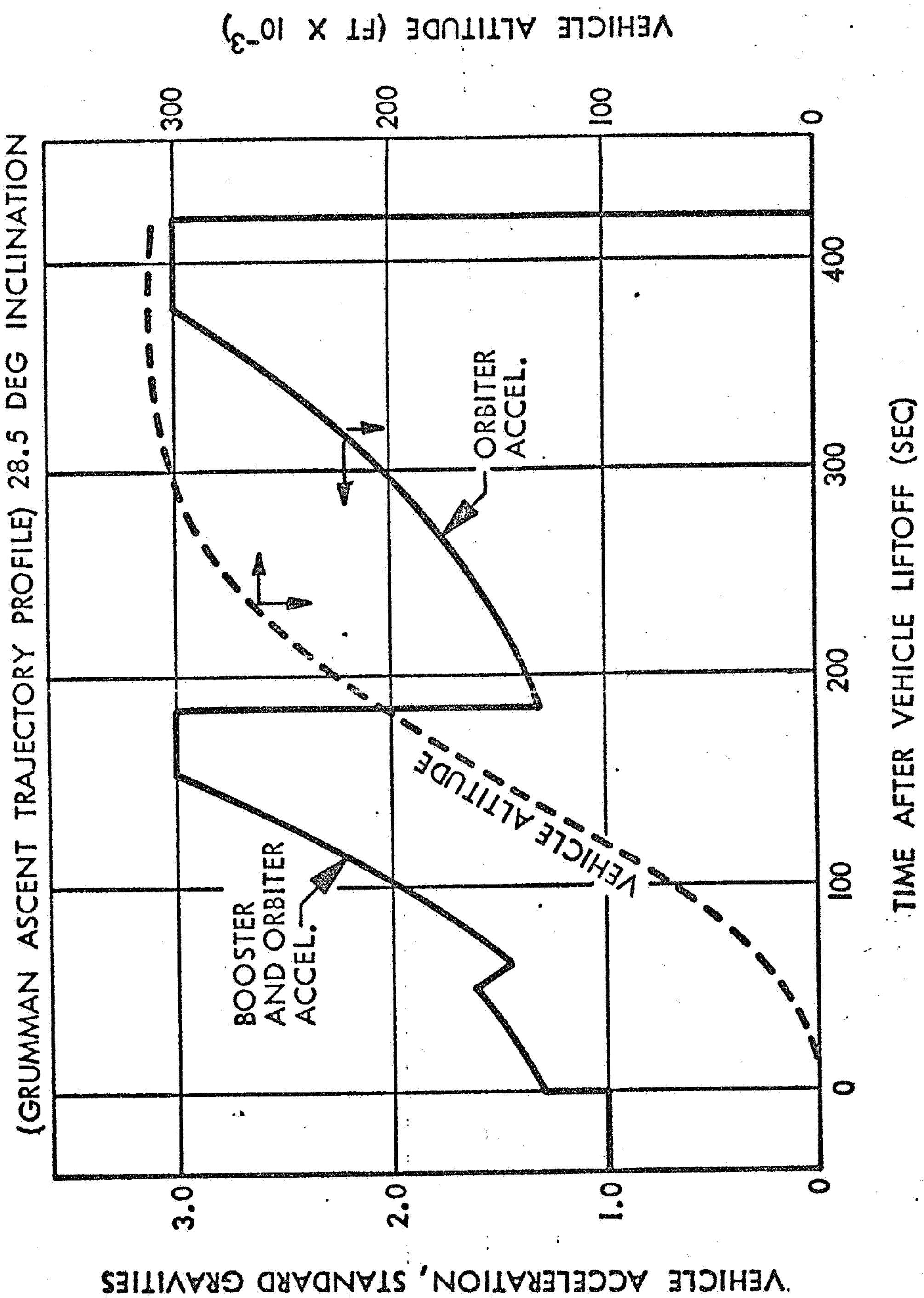


Fig. 12-2 Vehicle Acceleration and Altitude

D03828

Fig. 12-2

LOCKHEED

GRUMMAN DROPTANK WALL HEAT FLUX 3/4 IN. EXTERNAL FOAM INSULATION

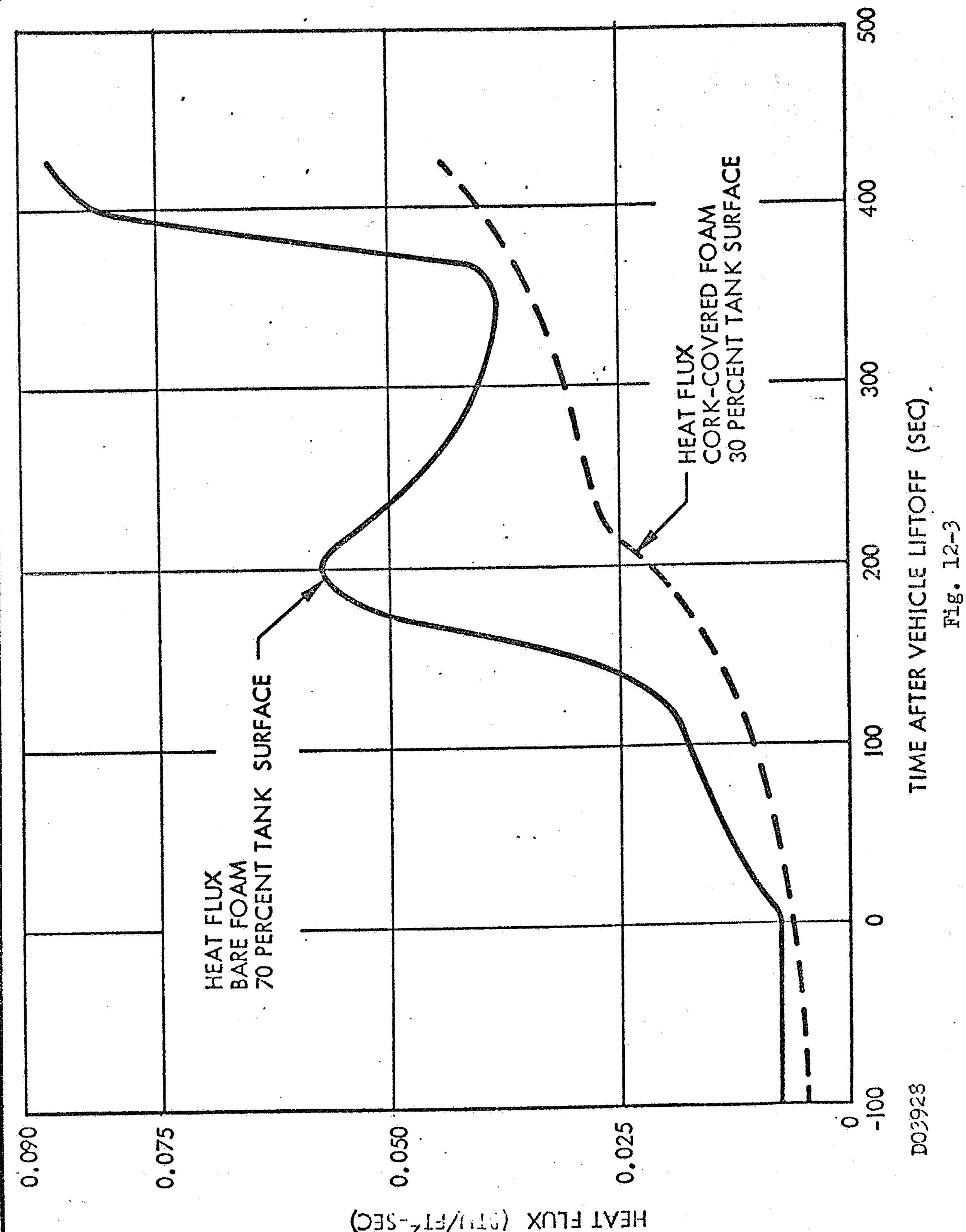


Fig. 12-3

DROPTANK TANK PRESSURE-TIME HISTORY
INSULATION THICKNESS - 3/4 IN.

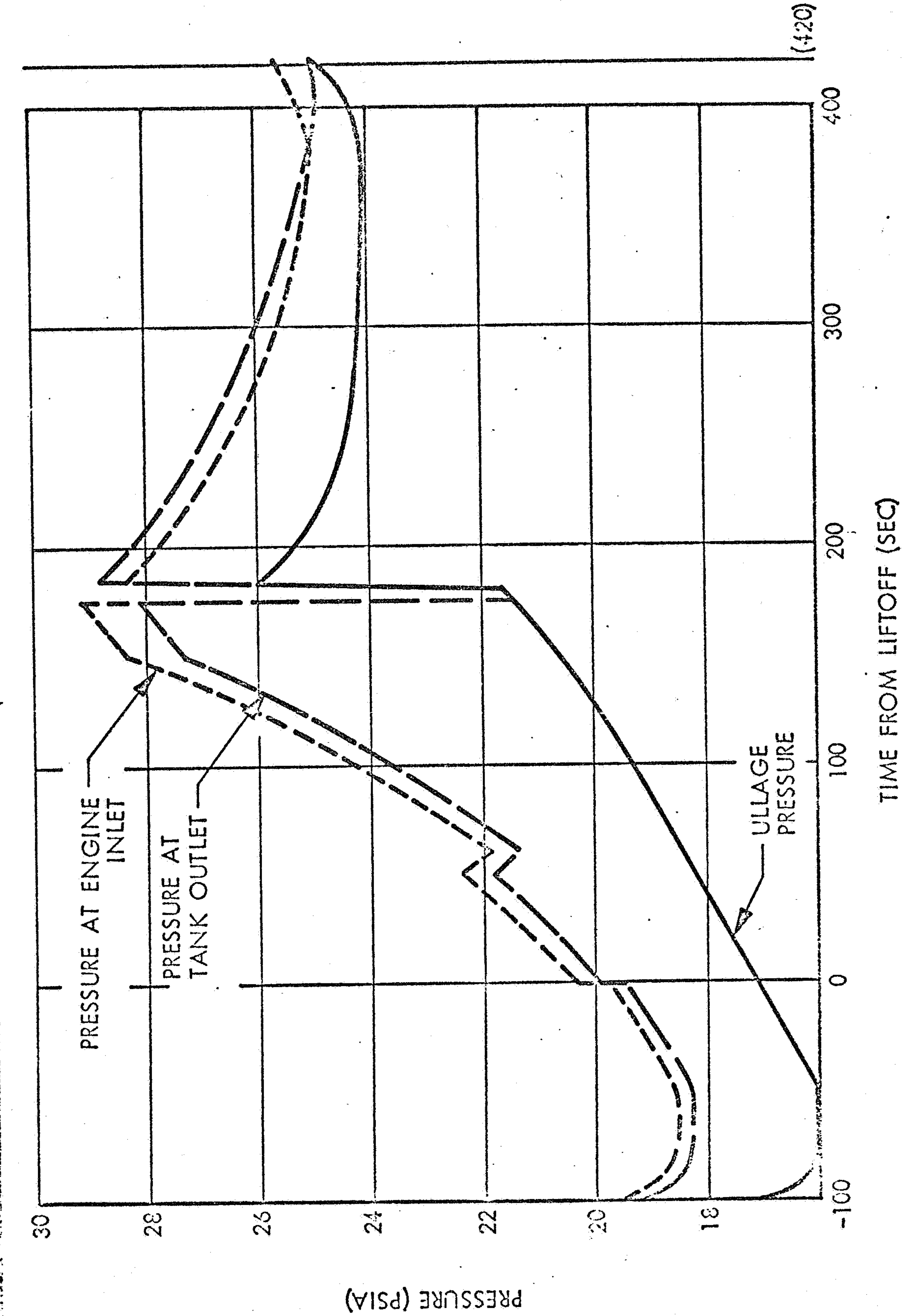


Fig. 12-4

Fig. 12-4

the rocket engine firing. At the end of rocket engine operation (time after liftoff $\approx$ 422 sec) the temperature of the liquid hydrogen draining from the tank has reached 38.9°R, which corresponds to a vapor pressure of 21 psia. Since NPSP requirements of 2 psi must continue to be satisfied, the ullage pressure of 25 psia coupled with the 3g acceleration provides a margin of 2.6 psi above the engine requirements or 4.6 psi above the hydrogen vapor pressure. In summary, it should be noted that requirements for venting during ascent (booster and/or orbiter operation) are minimal and with the proper selection of insulation thickness, ullage pressure limits and rocket engine pressurant bleed rate, venting may not be required. It follows, therefore, that the use of insulation systems designed for both ascent and reentry thermal protection will not impose more stringent functional criteria on the pressurization and venting system nor will it allow the removal of a subsystem or eliminate an operational function.

Upon completion of rocket engine operation, the hydrogen droptank remains attached to the orbiter stage for approximately 20 minutes before jettisoning. During this time period, residual liquid propellant, consisting of flight performance reserves and trapped liquids in the feedlines and in the rocket engines, is dumped overboard through the rocket engines. The hydrogen tanks thereafter contain only hydrogen vapor at 25 psia pressure and 240°R temperature which amounts to approximately 220 lbm. After completion of the liquid dumping phase and prior to droptank separation, some additional heat will be transmitted into the tank which will increase the vapor temperature and the pressure. Using data presented in EM L2-12-01-M1-13 it can be shown that the maximum pressure (includes a Safety Factor = 1.2) that the droptank can stand with a wall temperature of 300°R is 22 psig. Thus, the droptank must be vented to a lower pressure prior to separation from the orbiter stage, irrespective of whether intact entry is a design condition or not. A venting pressure level between 5 psia and 15 psia can be selected for purposes of orbiter protection which will also satisfy intact reentry criteria. On this basis, no special propulsion system modifications are required to accommodate an intact reentry of the liquid hydrogen droptanks.

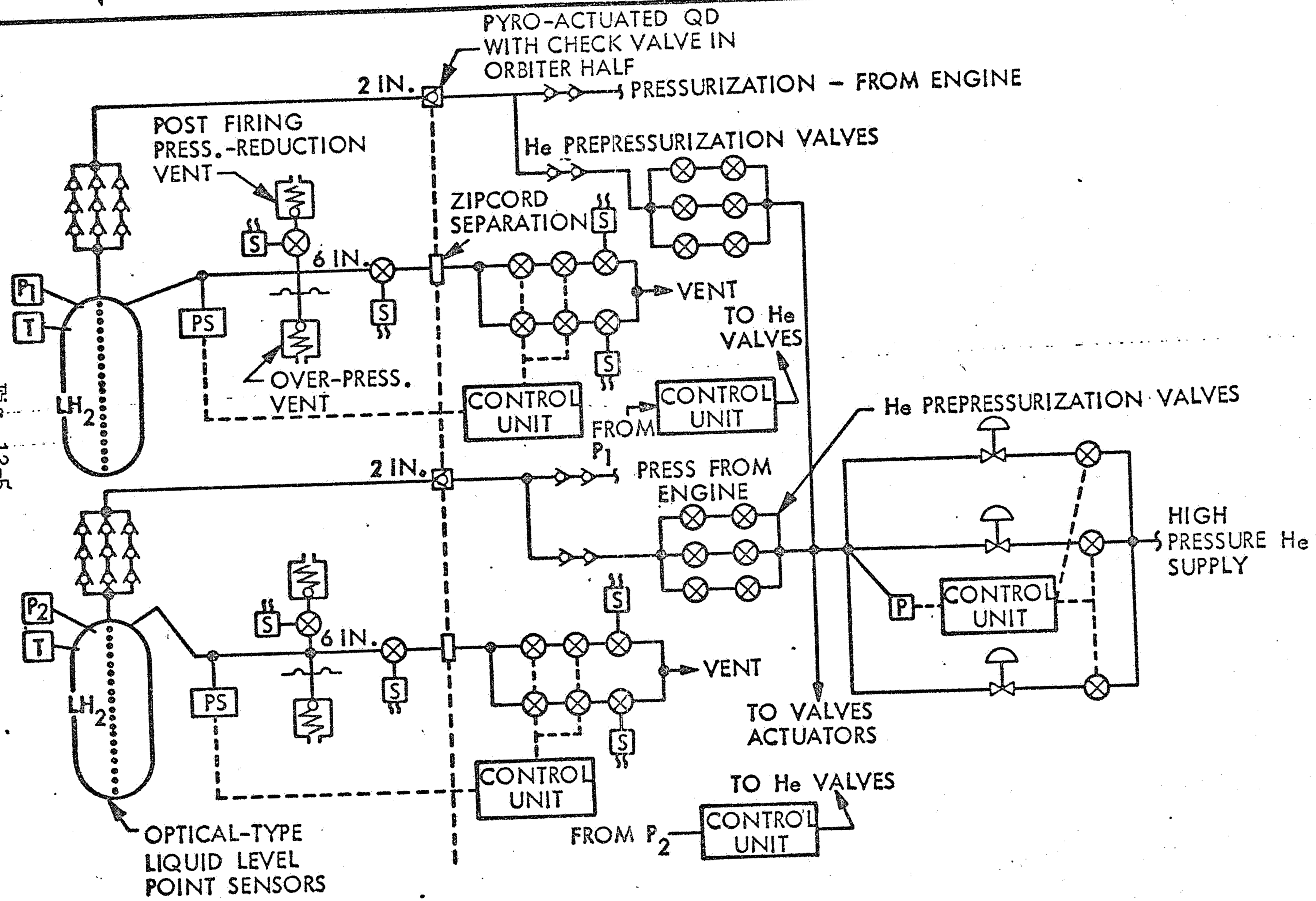
Plumbing and valves employed to implement pressurization and venting operations discussed in the preceeding paragraphs have been arranged schematically in Fig. 12-5. Note that the redundant arrangement of components satisfies fail-operational/fail-safe criteria specified by NASA for Space Shuttle mechanical systems. A more detailed presentation of the functions of individual valves, control circuits, and droptank timer commands is provided in the EM L2-12-03-M1-1 (see Appendix).

12.2 PROPELLANT FEED SYSTEM

Provisions for feeding liquid hydrogen propellant to the rocket engines were reviewed to support the design layouts associated with the costing effort to assue that all necessary functions involving tank purging, liquid propellant fill, and droptank drain had been accommodated. The droptank feed system schematic shown in Fig. 12-6 presents the propellant flow circuits and their associated components. Supplemental information concerning functions of individual valves and control circuits is contained in EM L2-12-03-M1-1 (see Appendix). Additional visualization of the position of the components and feedlines on the droptanks and in the orbiter stage can be obtained by reviewing LMSC layout drawings Nos. SKE 100720 (Fig. 9-2) and SKT 100723 (Fig. 17-2).

A separate investigation of a feedline and rocket engine chilldown system was performed to establish the impact of compliance with the prelaunch rocket chilldown requirements. Two basic arrangements of the propellant recirculation system were examined, one with forward circulation from the droptank through the feedline through the rocket engine pumps and return to the droptank via a recirculation line (Fig. 12-7), and the other circulation system (Fig. 12-8) with flow in the reverse direction. The result of this investigation is evident from the temperature rise curves presented in each figure which show essentially equal profiles at any circulation flow rate.

DROPTANK VENT AND PRESSURIZATION SCHEMATIC



D03642 (1)

Fig. 12-5

Fig. 12-5

DROPTANK FEED SYSTEM (INCLUDING RECIRCULATION)

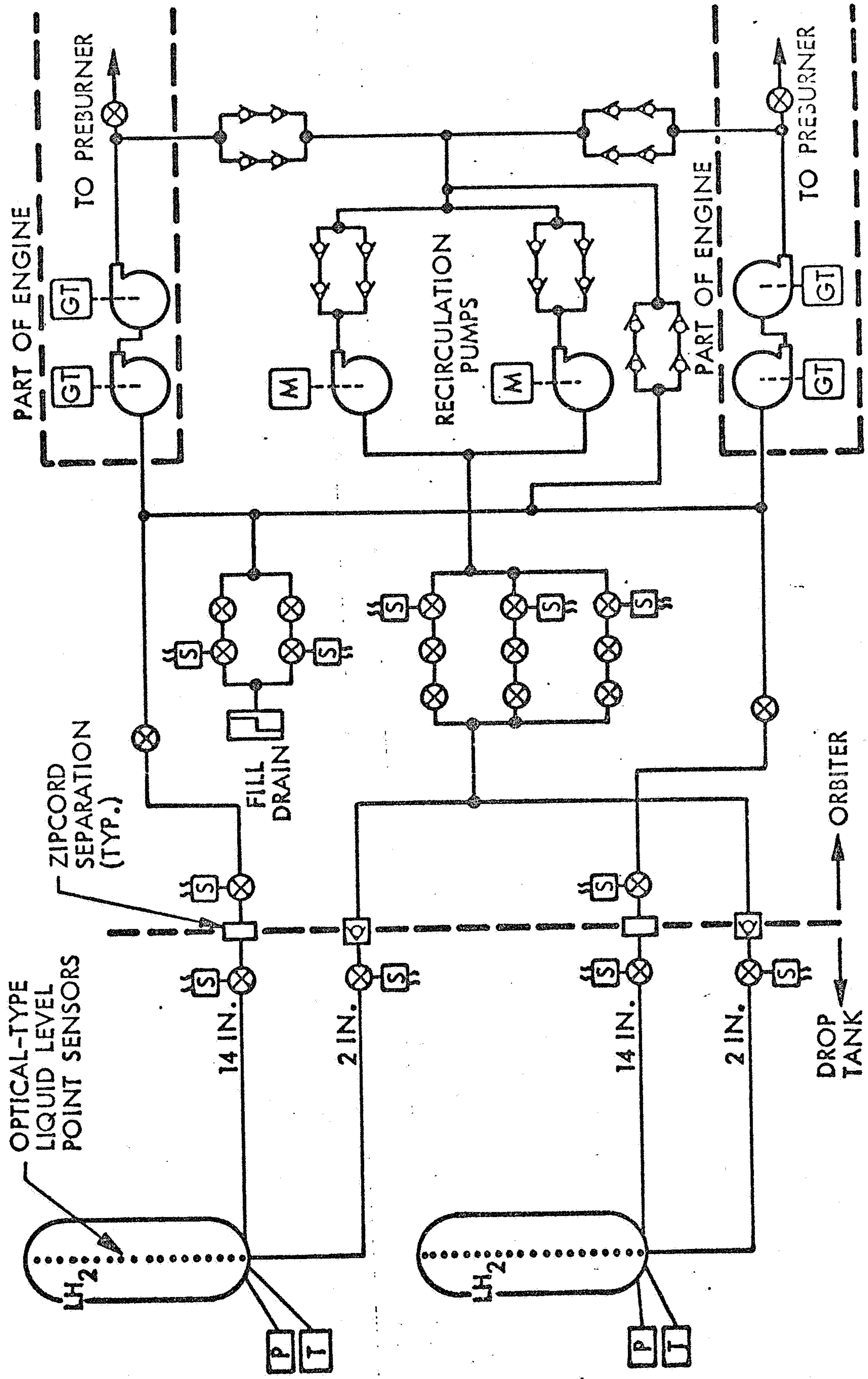
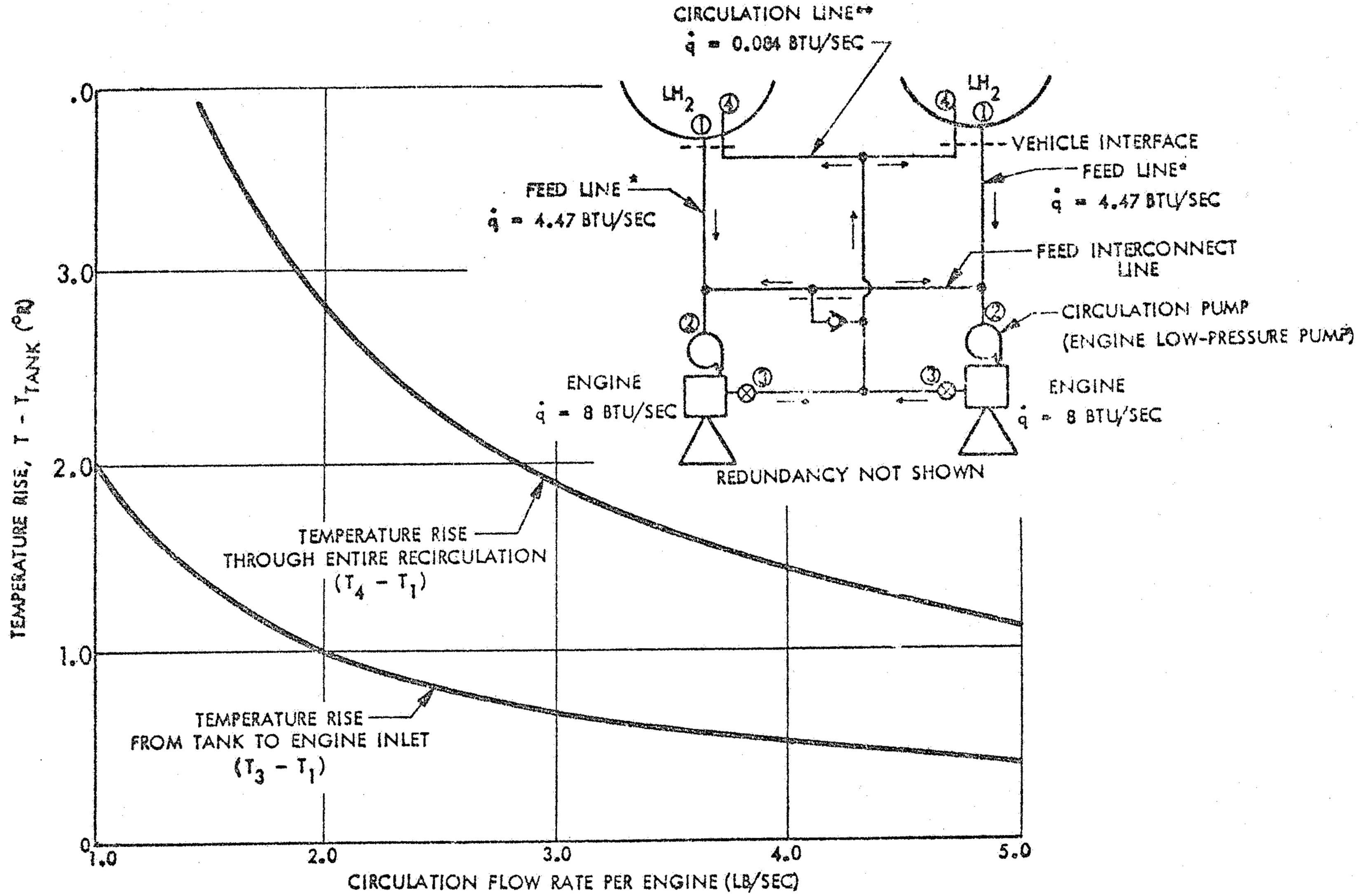


Fig. 12-6

D03643 (1)

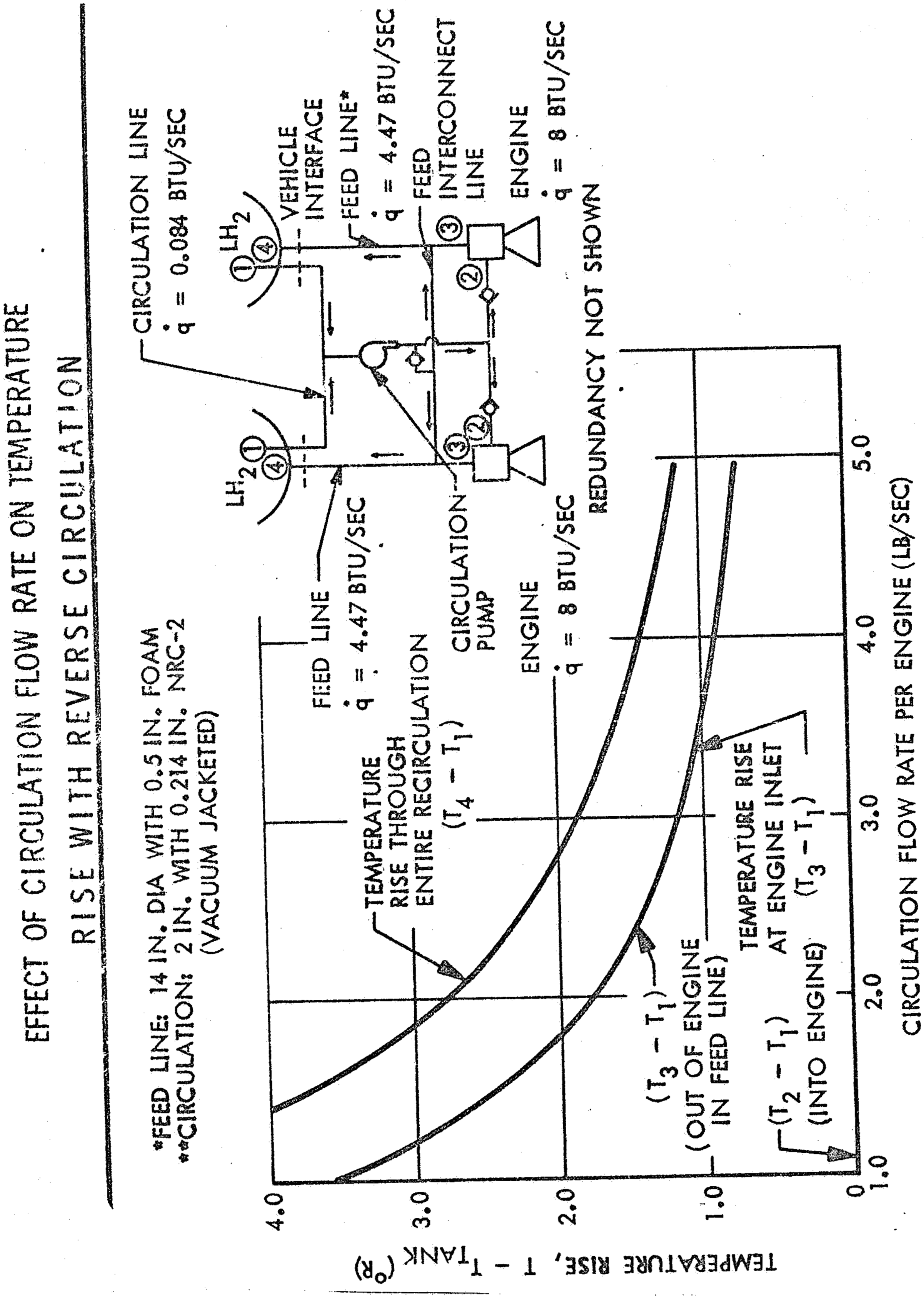
Fig. 12-6

EFFECT OF CIRCULATION FLOW RATE ON TEMPERATURE RISE WITH FORWARD CIRCULATION



*FEED LINE: 14 IN. DIA WITH 0.5 IN. FOAM
**CIRCULATION LINE: 2 IN. DIA WITH 0.214 IN. NRC-2 (VACUUM JACKETED)

Fig. 12-7



EFFECT OF CIRCULATION FLOW RATE ON TEMPERATURE RISE WITH REVERSE CIRCULATION
*FEED LINE: 14 IN. DIA WITH 0.5 IN. FOAM
**CIRCULATION: 2 IN. WITH 0.214 IN. NRC-2 (VACUUM JACKETED)
CIRCULATION LINE
q = 0.084 BTU/SEC
LH2
VEHICLE INTERFACE
FEED LINE*
q = 4.47 BTU/SEC
FEED INTERCONNECT LINE
ENGINE
q = 8 BTU/SEC
FEED LINE
q = 4.47 BTU/SEC
CIRCULATION PUMP
ENGINE
q = 8 BTU/SEC
REDUNDANCY NOT SHOWN
TEMPERATURE RISE THROUGH ENTIRE RECIRCULATION (T4 - T1)
(T3 - T1) (OUT OF ENGINE IN FEED LINE)
(T2 - T1) (INTO ENGINE)
TEMPERATURE RISE AT ENGINE INLET (T3 - T1)
TEMPERATURE RISE, T - TTANK (°R)
CIRCULATION FLOW RATE PER ENGINE (LB/SEC)
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0

Fig. 12-8

Thus, the direction of recirculation flow does not materially affect the functional design/operation of the liquid hydrogen droptank. A more extensive analysis of the recirculation system is presented in Ref. 12-1* and includes variations in feedline size, insulation thickness, vehicle plumbing configurations, and circulation flow rates.

12.3 PLUMBING SEPARATION

Separation of droptank propellant and pressurization feedlines has been examined from the standpoint of technical feasibility and reusability. Two contrasting concepts are (1) the reusable disconnect coupling having a checkvalve feature in each valve-half, and (2) expendable/replaceable coupling, severed by a pyrotechnic device, in conjunction with separate shutoff valves for propellant isolation on each side of the separation joint. These two concepts are presented in Figs. 12-9 and 12-10, respectively. Some of the alternate disconnect concepts which have been considered are illustrated in Fig. 12-11. It is reasoned that reusable disconnects of the sizes considered for the liquid hydrogen feedline may be susceptible to damage during the separation sequence and thermal distortion during reentry so that some refurbishment would be required upon completion of each mission. The expendable section, however, would be replaced at relatively low cost for each mission. In operation and prior to line separation, propellant isolation valves on each side of the disconnect are closed. The valve on the droptank side will be designed for high actuation reliability, but some leakage can be tolerated since tank venting to relieve pressure buildup in the residual hydrogen vapor will be required anyway. A multiple explosive cord design can be used with redundancy in the electrical circuits and pyrotechnic components to obtain high reliability. Lockheed has had considerable experience in this field and devices in production are regularly used in space flight missions.

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*LMSC-A989469, 8th Monthly Progress Report, Contract NAS 9-11330, Shuttle Cyrogenic Supply System Study

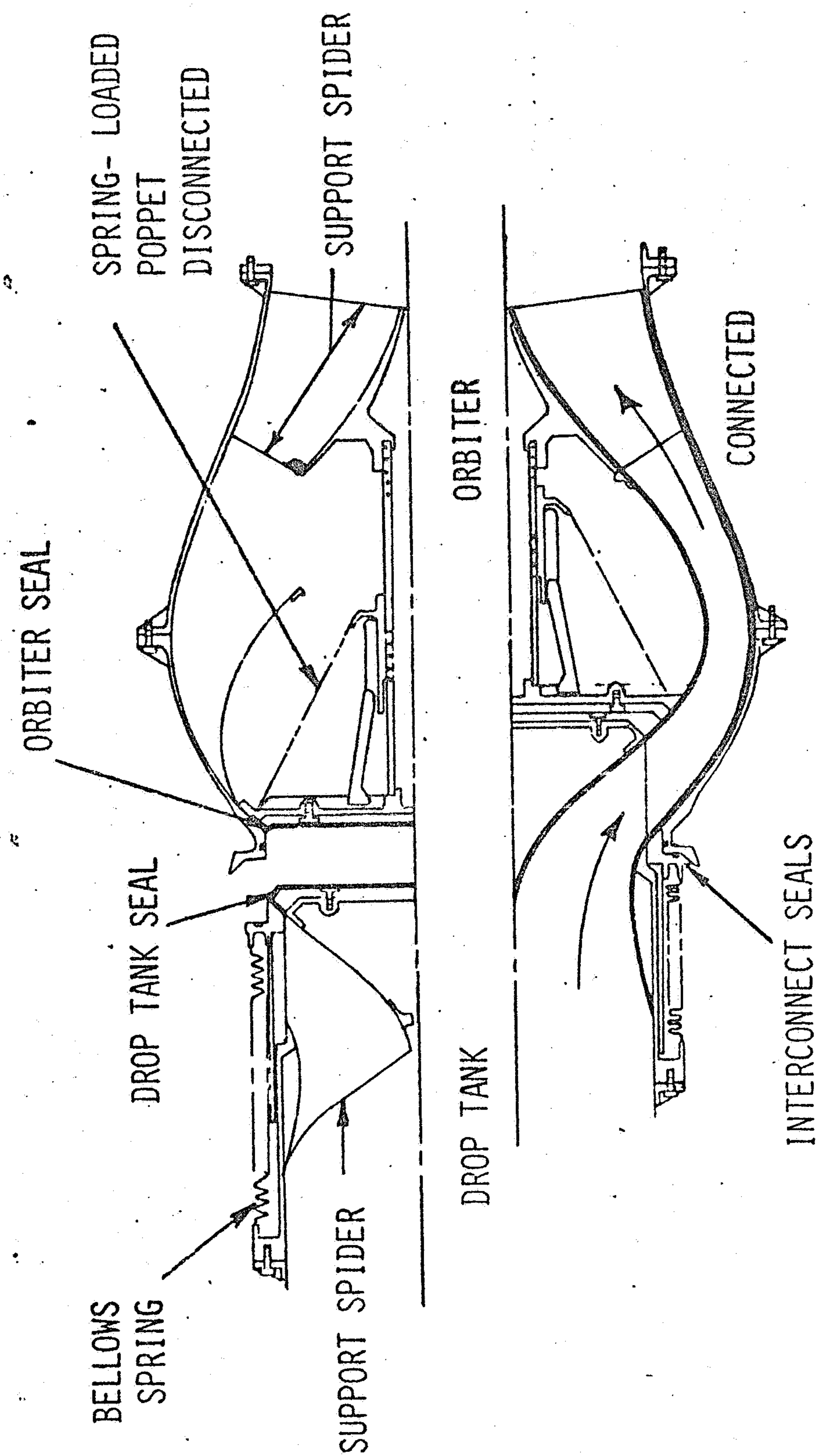

Fig. 12-9 External Tank Orbiter - Disconnect Valve-Design Detail

Fig. 12-9

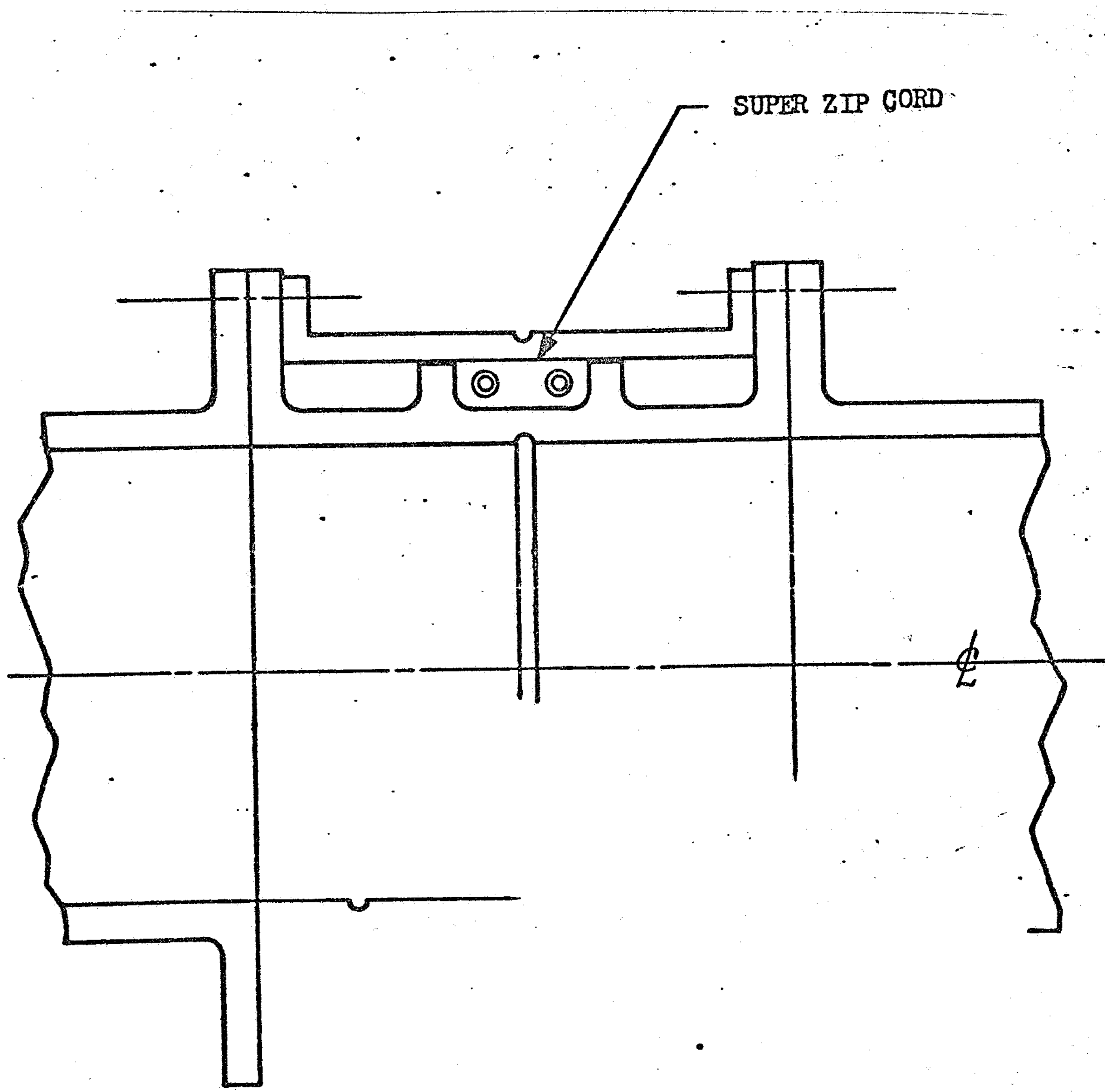

Fig. 12-10 Expendable Explosive - Cord Disconnect

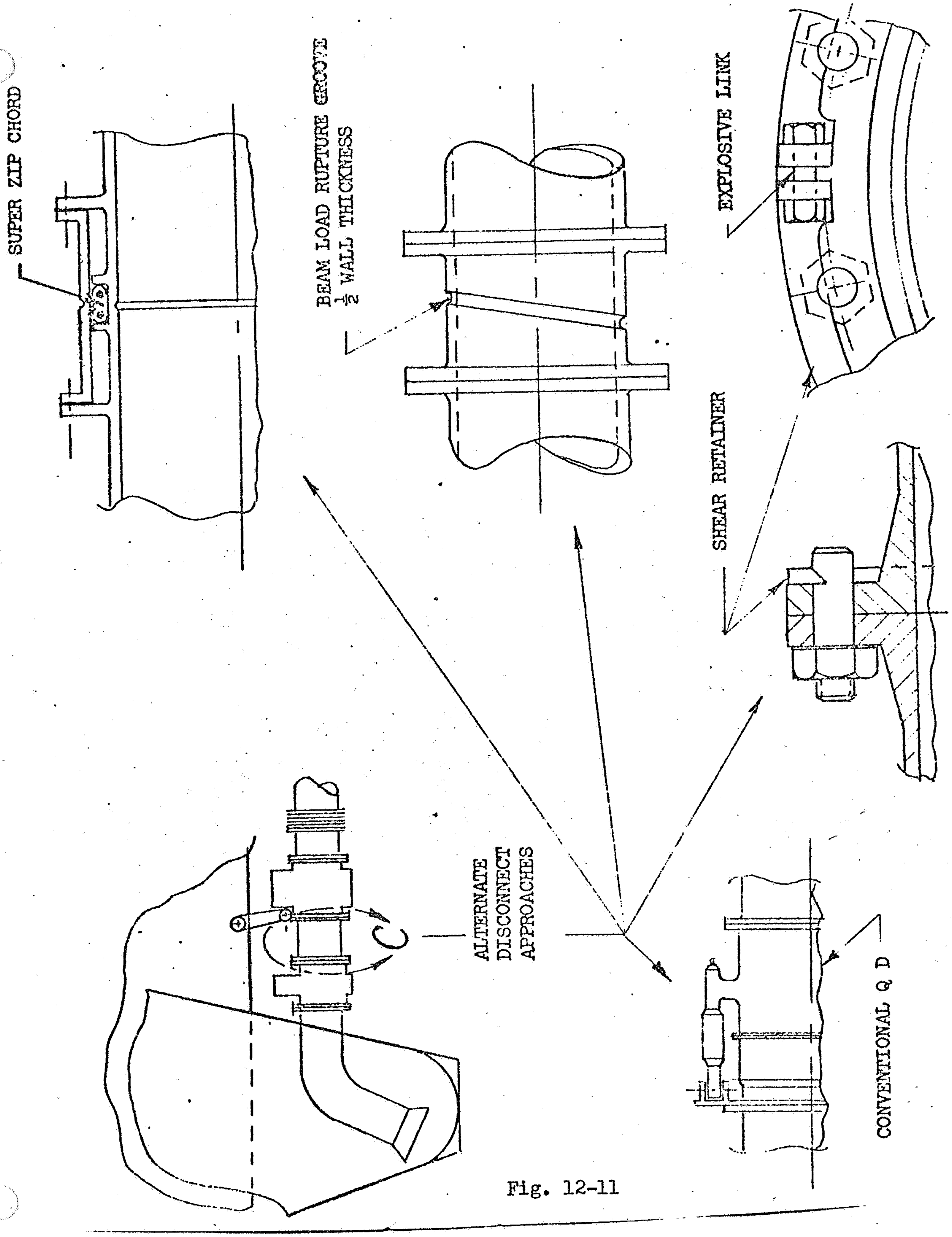

Fig. 12-11

Fig. 12-11 Alternate Droptank Separation Approaches

12.4 PROBLEM AREAS

Propulsion system analyses and design investigations conducted as part of this study effort have served to confirm earlier estimates of droptank ullage pressure criteria and to define plumbing arrangements for pressurization, venting, and propellant feed to satisfy Space Shuttle program critera for FO/FS functional reliability. Based on these studies, addtional tasks have been identified which should be performed to further clarify the design limits and operational bounds of the propulsion systems.

These tasks or problem areas are as follows:

(1) Further analysis of hydrogen propellant stratification in conjunction with the selected insulation system to define minimum ullage pressure limits. Tank pressure levels should be analyzed for post-burn/pre-separation and for post-separation/reentry phases.

(2) The effects of recirculation flow rates and temperature rise on propellant stratification require investigation.

(3) The location of pressurization/venting disconnects forward or aft on the orbiter warrant further analysis from system weight, drop-tank cost, and separation dynamics standpoints.

(4) The application of reusable versus expendable plumbing disconnects should be further investigated with more attention given to variations in the line size, technology status, production/refurbishment costs, and the impact of design selection on separation sequence and dynamics.

(5) The production status of cost of both existing and new retrorocket motors should be further evaluated.

12.5 VENT/PRESSURE LINE ROUTING COMPARISON

The vent/pressure line which runs between the orbiter propulsion system and the forward end of each droptank (see Section 9.1, Fig. 9-2 for layout) can be routed either along the outside of the tank and through the orbiter skin at the same point as the large LH_2 feedline or it can be routed through the oribter skin adjacent to the forward end of the tank and run down the inside of the orbiter. For the line on the outside of the tank, one line is required for each tank and is expended with the tank. For the line on the inside of the vehicle only, one set of lines for each orbiter is required and the line is not expended but recycled as part of the orbiter turnaround maintenance. The tradeoff study results shown in Table 12-1 show the effect of both the methods described.

A savings of approximately $18 million is realized by routing the vent/pressure line inside the oribter and reusing it. This savings results primarily because of the differences in production costs of the line. The 50 percent maintenance factor shown for this subsystem is very conservative and probably can be greatly reduced, thereby producing even greater savings for the reusable line approach.

12.6 FEEDLINE DISCONNECT METHOD COMPARISON

Two types of feedline disconnects were investigated - a single piece quick-disconnect valve and a pipe spool with pyrotechnic cutter between two shut-off valves (see Section 12.3, Figures 12-9 and 12-10). Various pryotechnic cutting systems were studied, but no significant cost difference or reliability was found, so only one pyrotechnic device was traded off against a standard quick-disconnect valve. The results are presented in Table 12-2. The pyrotechnic system shows an approximate program saving of $3.5 million due to its lighter weight, lower production cost, and lower maintenance cost. Both systems retain about the same weight on the orbiter after tank separation, but the higher cost and weight of the expended quick-disconnect valve half gives the simpler pyrotechnic system the greater cost advantage.

LOCKHEED

VENT/PRESSURE LINE ROUTING TRADE STUDY

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	LINE ROUTING	
	OUTSIDE TANK	INSIDE VEHICLE
PRODUCTION COST	$ 36.3	$ .3
MAINTENANCE COST	$ 0	$ 18.1
COMPARISON TOTAL	$ 36.3	$ 18.4
RELATIVE COST	REF	$-17.9

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Table 12-1

Table 12-1

LOCKHEED

LH_2 FEEDLINE DISCONNECT METHOD TRADEOFF STUDY

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	TYPE OF SUBSYSTEM	
	SPOOL WITH PYRO CUTTER	QUICK-DISCONNECT VALVE
* DISCONNECT WEIGHT	(215 LB) REF WT	(400 LB) $ 1.5
PRODUCTION COST	$ 4.1	$ 5.4
MAINTENANCE COST	$ 0.4	$ 1.1
COMPARISON TOTAL	$ 4.5	$ 8.0
RELATIVE COST	REF	$+3.5

* DROPTANK WEIGHT SENSITIVITIES – $8,000/LB

Table 12-2

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Table 12-2

Section 13
ELECTRICAL SYSTEM

13.1 DESCRIPTION

The droptank electrical system includes instrumentation and controls for fuel management and preparation for deployment, the initiation of explosives for separation and ejection, the determination of a safe attitude for retrorocket firing, the initiation of retrorocket firing, and the electrical energy source to support these functions.

A block diagram showing the functions of the droptank electrical system and its relation to the orbiter is shown in Fig. 13-1. The electric power source for the droptank consists of two batteries which are connected into the electrical system 2 sec prior to the separation sequence. Up to that time, power for any fluid instrumentation and control is supplied by the orbiter electrical power system which is assumed to be a 28-volt system. Battery 1 is a 110-ampere hour 28-volt battery capable of supplying the droptank electrical power requirements. Battery 2 is an identical battery for redundancy. Diodes in series with each battery output prevent defects, such as internal battery shorts, from affecting the output of the remaining battery.

Power transfer control is actuated 2 sec prior to initiation of the droptank separation sequence. At this time, the integral droptank timer is reset. The actual separation sequence is initiated by the parent vehicle data management/ guidance computer. The initiation is dependent upon the parent vehicle achieving correct attitude and orbit position to achieve the desired impact zone after a fixed retro sequence. The initiation of this sequence is thus under vehicle system control.

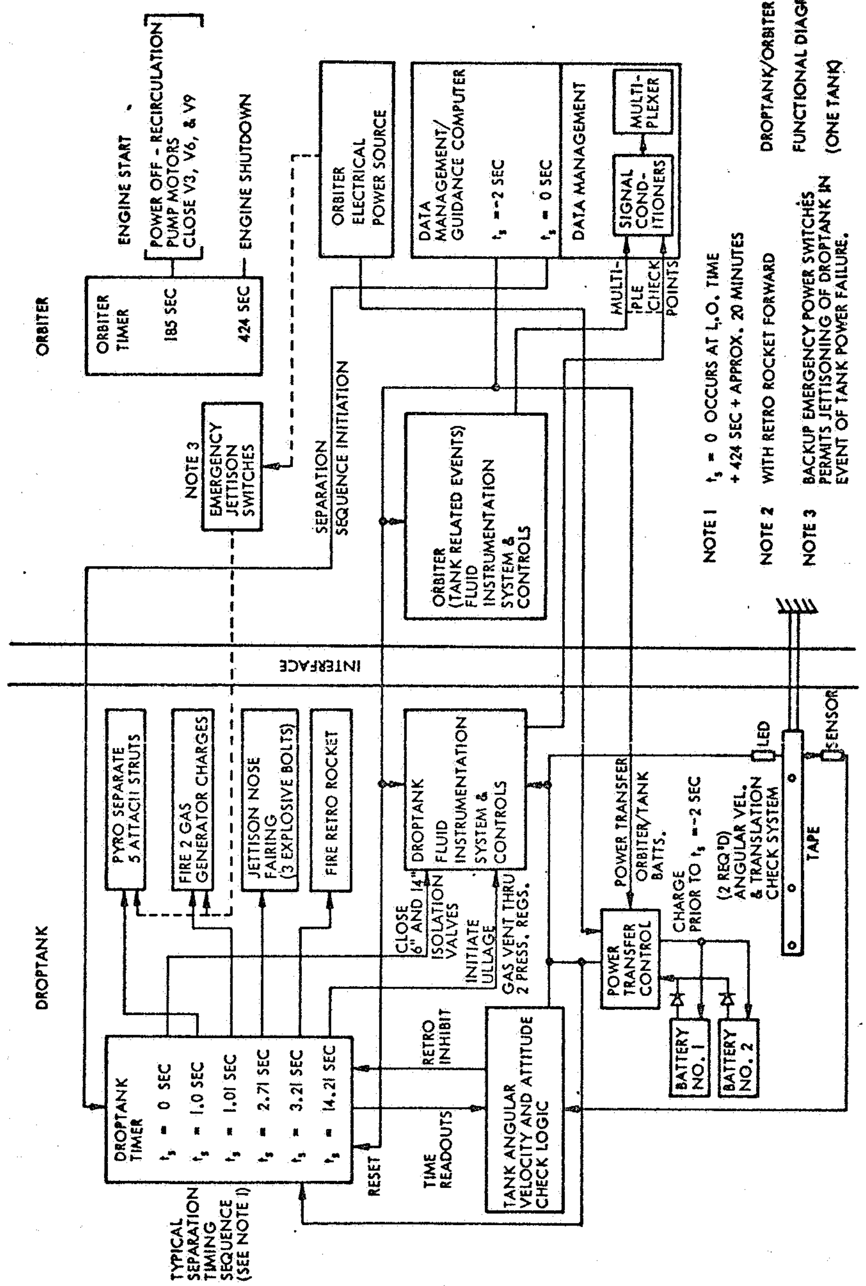

Fig. 13-1 Droptank Electrical System Block Diagram

As the droptank is deployed, the tank angular velocity and attitude check system operates to assure safety of the orbiter and proper tank attitude to hit the projected droptank dispersion area when the retrorocket is fired. This is described in more detail in Section 13-3 on the retrorocket system, and it is shown in the functional diagram as the angular velocity and attitude check logic with associated tape-sensing systems.

13.2 FLUID INSTRUMENTATION AND CONTROLS

The location of system hardware was influenced strongly by the need to minimize the amount of hardware jettisoned. Therefore, as much of the hardware as possible is located on the orbiter side without compromising the operational requirements of the system. An effort was also made to minimize system weight, length of lines, and system complexity, while meeting the fail-safe/fail-operational requirements.

Squib-actuated valves were selected for one-shot applications, thus taking advantage of the high reliability and high power/weight ratio inherent in squib actuators.

Figures 13-2 and 13-3 indicate the system fluid control hardware and instrumentation. All pressure transducers, temperature transducers, and pressure switches are quad-redundant. Single optical-type liquid level sensors are located at the following volumetric levels in each tank: 2%, 3%, 10%, 20%, 40%, 50%, 60%, 70%, 80%, 90%, 97%, 98%, 99%, and 101%. Four liquid level sensors each are mounted at the 1% and 100% volumetric levels.

Table 13-1 used in conjunction with Figs. 13-2 and 13-3 describes the combined vehicle and droptank system and their operation up to tank separation. Figure 13-4 indicates commands originating from the vehicle and resulting events.

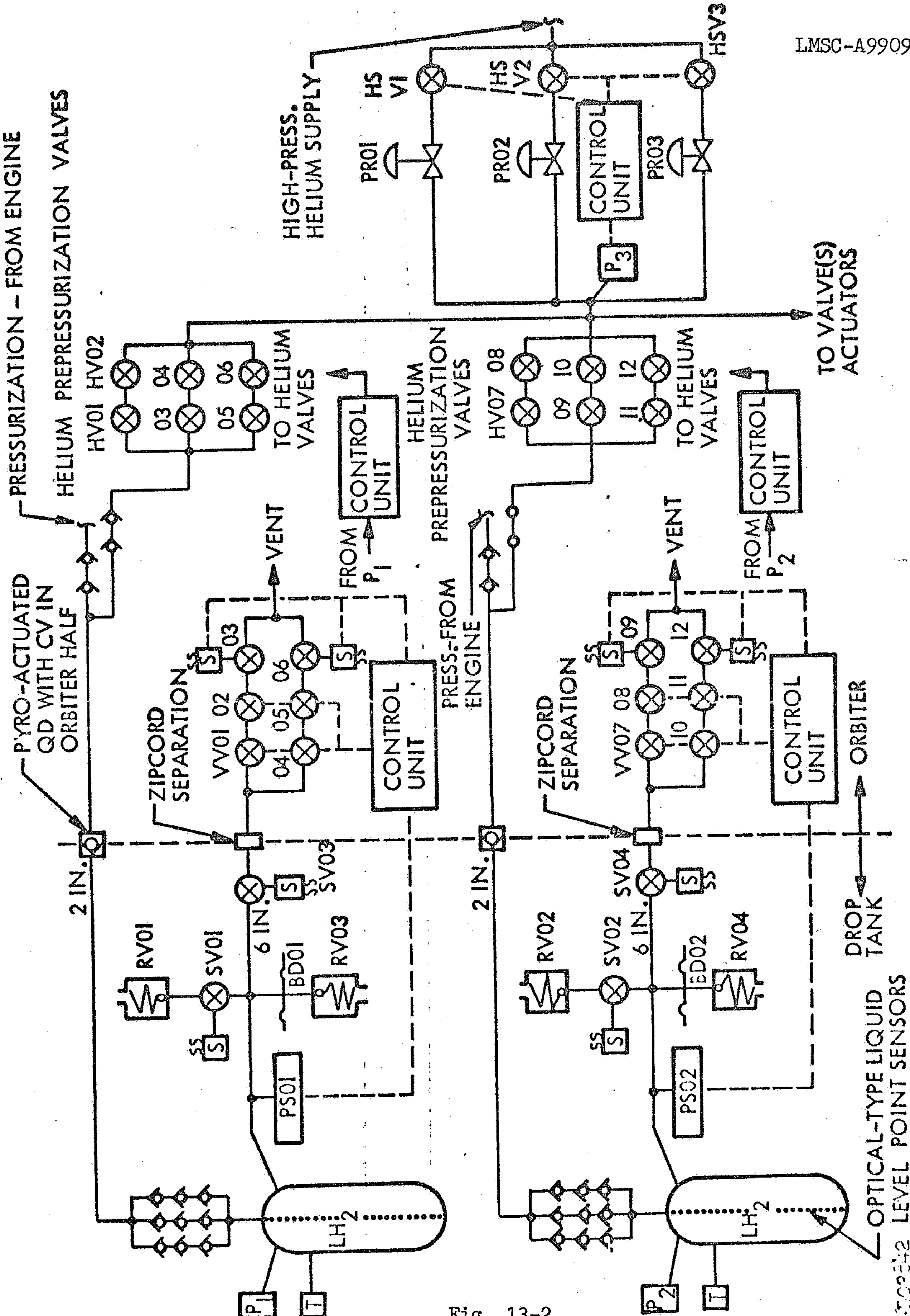

Fig. 13-2 Droptank — Vent and Pressurization System

Fig. 13-2

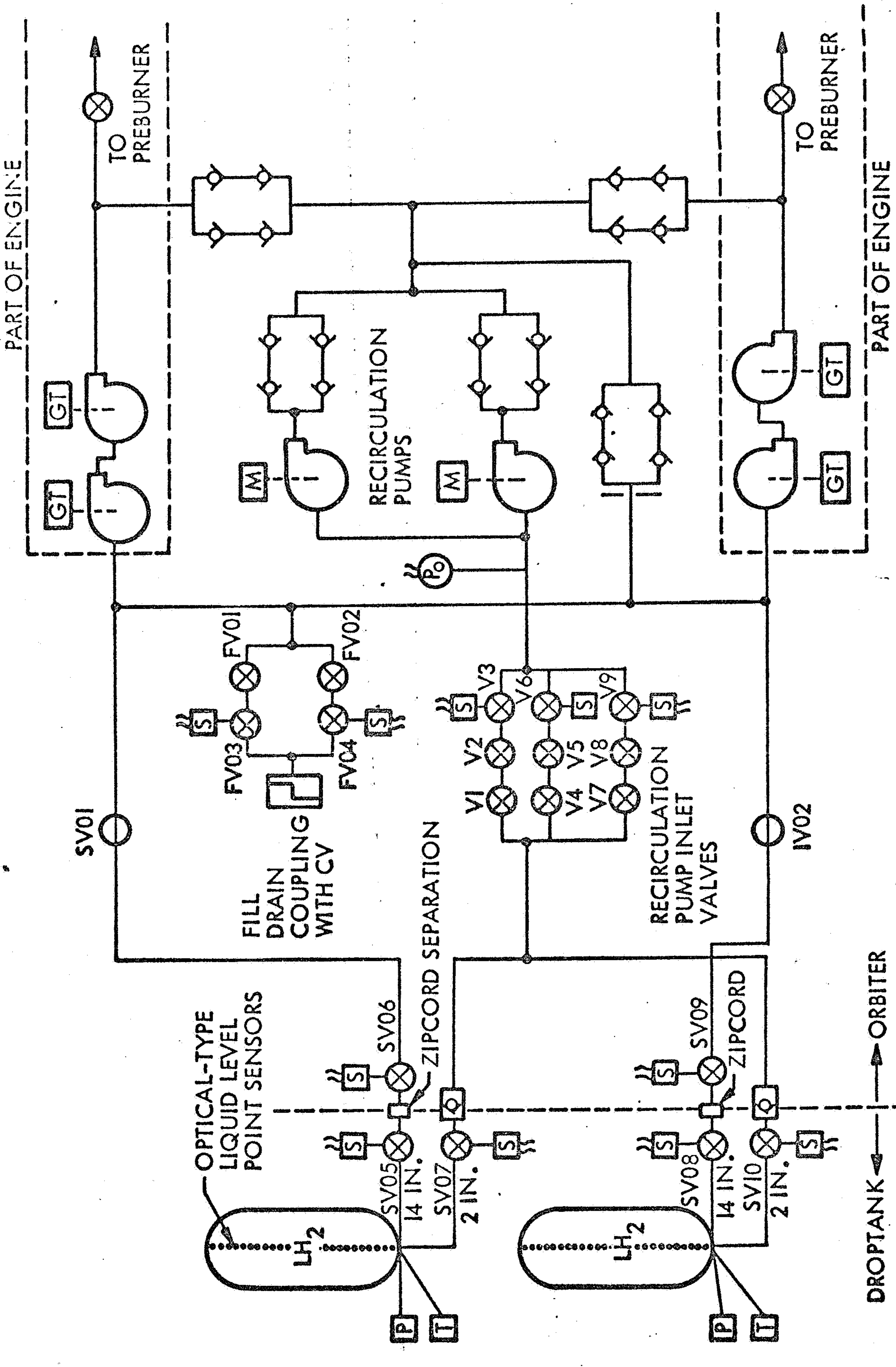

Fig. 13-3 Droptank - Feed and Circulation System

Fig. 13-3

In addition to ground-commanded events prior to liftoff, there are four automatic control loops: (1) recirculation pumps inlet pressure, (2) helium prepressurization, (3) helium regulation, and (4) tank vent pressure.

Table 13-1

System Operation Analysis

COMPONENT OR SUBSYSTEM *	CONDITION
SV01 and SV02	Closed until post-separation pyro actuation.
RV01 and RV02	Inactive until SV01 and SV02 actuated.
SV03 and SV04	Normally open until pre-separation command from guidance computer.
PS01 and VV01 thru VV06 PS02 and VV07 thru VV12	Active during Ground Prepressurization Operation only.
P3 and HSV1 — HSV3	Active from Start of Fill Operation thru Separation.
Liquid Level Sensors	Active from Fill thru Separation.
SV06 thru SV10	Normally Open - Pyro-actuated closed prior to separation via orbiter guidance computer.
FV01 and FV02	Open only during Fill Operation.
FV03 and FV04	Normally Open - Pyro-actuated close upon completion of Fill.
IV01 and IV02	Open from Start of Fill to Engine Off Command.
P_o and V1 — V9	Active from Start of Fill up to Engine Start Command.

* See Figs. 13-2 and 13-3

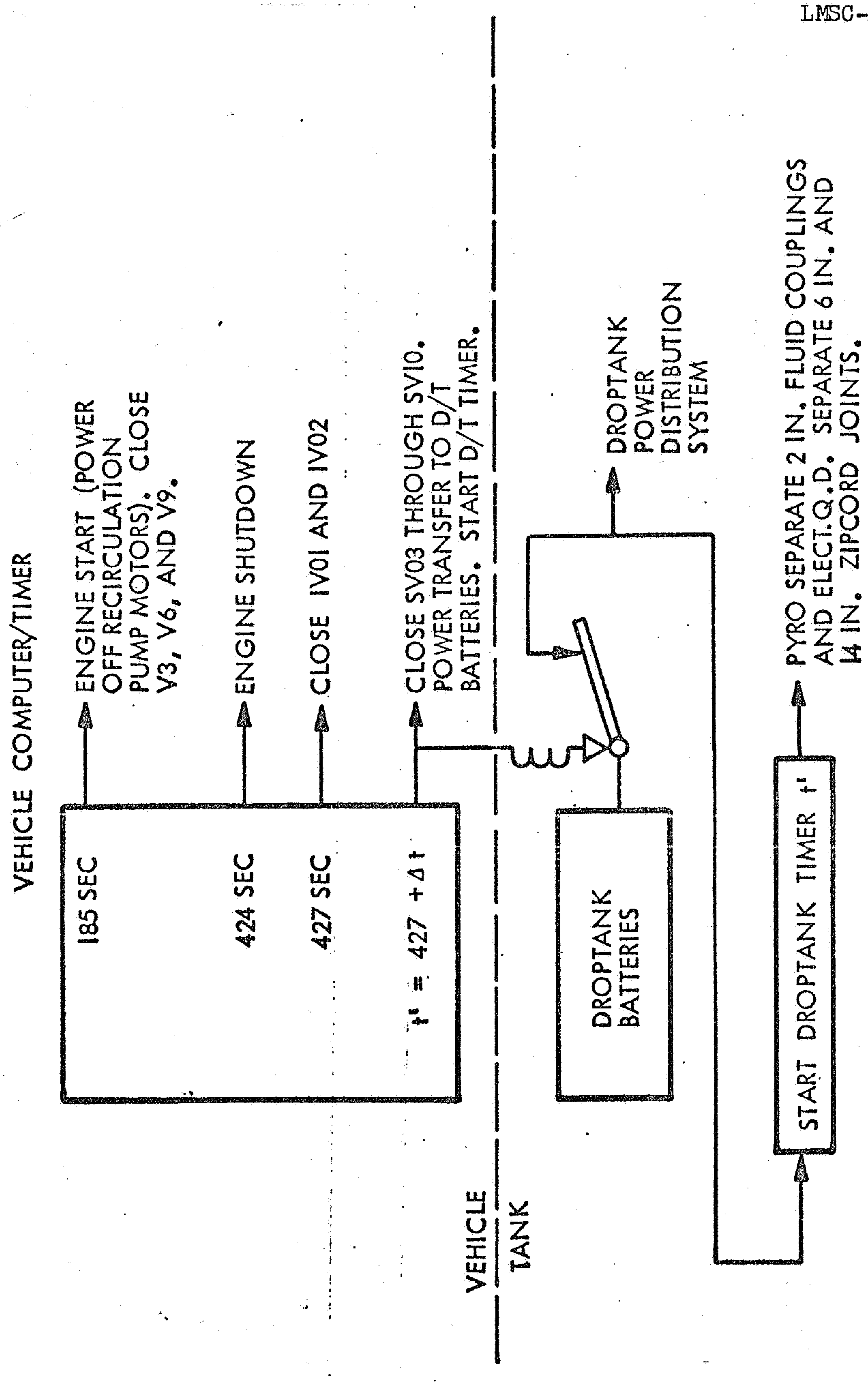

Fig. 13-4 Vehicle Timer Command Events

Fig. 13-4

13.3 RETROROCKET SYSTEM

13.3.1 Objective

After vehicle initiation of the retro sequence, the purpose of the retrorocket electrical system is to provide a method of firing the droptank retrorocket after separation from the orbiter to insure dispersion of the tank over the chosen target area. In addition, the system must do so with assurance of safety to the orbiter.

13.3.2 Assumptions

- Tanks are jettisoned between 50 and 100 nm during coast.
- Both tanks are separated from the orbiter simultaneously.
- A typical timed sequence of events at separation would be as follows. It assumes that all propellant system events have been completed ($t_s = 0$ is initiation of separation events and is started by the data management/guidance computer at 424 seconds + approximately 20 minutes after liftoff).

$t_s = 0$	Pyro-separate 2-in fluid and electrical quick disconnects. Separate zip joints.
$t_s = 1.00$ sec	Pyro-separate five attach struts.
$t_s = 1.01$ sec	Fire two gas generator charges
$t_s = 2.71$ sec	Jettison nose fairing (3 explosive bolts).
$t_s = 3.21$ sec	Fire retrorocket.
$t_s = 14.21$ sec	Initiate ullage gas through two pressure regulators.

- The droptanks attach to orbiter at two points near the tank's nose and tail, and separation impulse is by means of two gas generators at these points, acting through the local axial center-of-mass.

- The droptanks should preferrably be a minimum of one tank length away from the orbiter at retrorocket firing.
- High acceleration (in the order of 5g) is preferred over low-g ejection.
- Each droptank will be ejected with an impact of 56,000 lb for 0.2 sec (11,320 ft/sec) provided by the gas generators.
- To hit the target area and to provide safety to the orbiter, the attitude of the longitudinal axis from the desired trajectory will be within $\pm$ 3 deg. Present angular velocity limits are assumed to be no greater than 3 deg/sec.
- It is assumed that a minimum system that has high probability of the droptank falling within the target area while satisfying minimum safety constraints is desirable aboard the tank.
- As further investigation reveals safety enhancement to be desirable, the system should be capable of expansion to accommodate these requirements.

13.3.3 Possible Approaches

One approach to retrorocket firing is to have a timer aboard the droptank which will initiate firing at $t_s = 3.21$ sec when the tank will have deployed one tank length away from the orbiter. However, this approach assumes the tank is in the correct attitude.

A further restraint on firing of the retrorocket is to check the attitude of the droptank along its longitudinal axis in one degree-of-freedom in the ejection plane; i.e., a plane that goes through the longitudinal axis of the gas generators. Some maximum angular velocity would be a constraint on the timer firing the retrorocket.

Further checks on the attitude of the droptank prior to firing could be added by checking its attitude in more degrees-of-freedom. Using limits on these attitudes could be further restraint in allowing the timer to fire the retrorocket. Increased sophistication in the direction of increasing checks of attitude, as described, represents increasing cost of a throwaway system.

An added refinement is to check angular velocity of the droptank as it leaves the orbiter, and if the maximum angular attitude will be reached earlier than one-tank length away, but greater than some minimum distance, say 2/3-tank length from the orbiter, allow the retrorocket to fire early. The minimum distance could be determined by not allowing firing until a calculated time had elapsed corresponding to this minimum or it could be based on actual translation velocity measurements. Normal firing would take place at one-tank length or selected distance if angular velocity limits were not reached.

A radio-frequency link (UHF or S-band) could be used in two ways between the orbiter and the droptank. One way is to give the astronaut manual inhibit override capability so that he may fire the retrorocket if it becomes visually obvious that the attitude of the droptank is out-of-limits. It appears that this would be precluded at the high-ejection impulse assumed. If a lower g ejection were used requiring the order of 8 to 10 sec for the droptank to get one-tank length away from the orbiter, this approach would be possible. A second use of a UHF or S-band radio-frequency link would be as a manual backup to firing of the retrorocket after jettisoning if the automatic firing system failed and the attitude of the droptank appeared normal to the astronaut. Encoders at the orbiter transmitters and decoders at the droptank receiver outputs would be used. In connection with either of these uses of a radio link, strip lights would be required along the droptank length so that the astronaut could observe its attitude if ejection occurred in darkness.

13.3.4 Selected Baseline

The solution uses checks, after jettisoning occurs, on the rate of angular velocity and on the angle of the tank in relation to the orbiter's trajectory in the ejection plane; i.e., a plane through the longitudinal axis of both gas ejection chambers. If these checks are both within limits, the timer is permitted to proceed through its timing sequence and fire the retrorocket. At present, these checks appear to be adequate as the largest expected error in attitude is in the ejection plane.

13.3.5 Attitude and Angular Velocity Check System

As shown in Fig. 13-5 , the main components of the system are two light-emitting diodes (LEDs) used as light sources, with associated photo transistor sensors, two tapes approximately 10-ft long with lead ends attached to the orbiter by means of structural wires, and the timer and registers with arithmetic logic.

The two tapes are stored either in long tubes or cylinders and are located at either end of the droptank (approximately 80-ft apart), and the tapes are in the same plane as the ejection plane through the two gas-ejection generators. As the tank is deployed, identical holes in each tape are sensed. There is a sensing hole immediately inside the sensor station, say at 1 in; then precisely 8-ft and 10-ft down the respective tapes, two more holes. These must be sensed after the ejection-impact pulse is over. Sensing of the holes causes the time to be stored in the registers shown. The first hole to be sensed in either tape reads out time t_1. However, the time at which 8-ft and 10-ft mark are sensed on both tapes is stored (see Fig. 13-5). Briefly, the calculations made are:

$$v_1 = \frac{s_2 - s_1}{t_3 - t_2}, \qquad v_2 = \frac{s_2' - s_1'}{t_3' - t_2'} .$$

Angular velocity of the droptank equals $\left[\frac{v_2 - v_1}{r} \right]$, where r = distance between tapes. The minimum angular velocity is set up as a limit on one comparator and is one of the conditions on firing of the retrorocket.

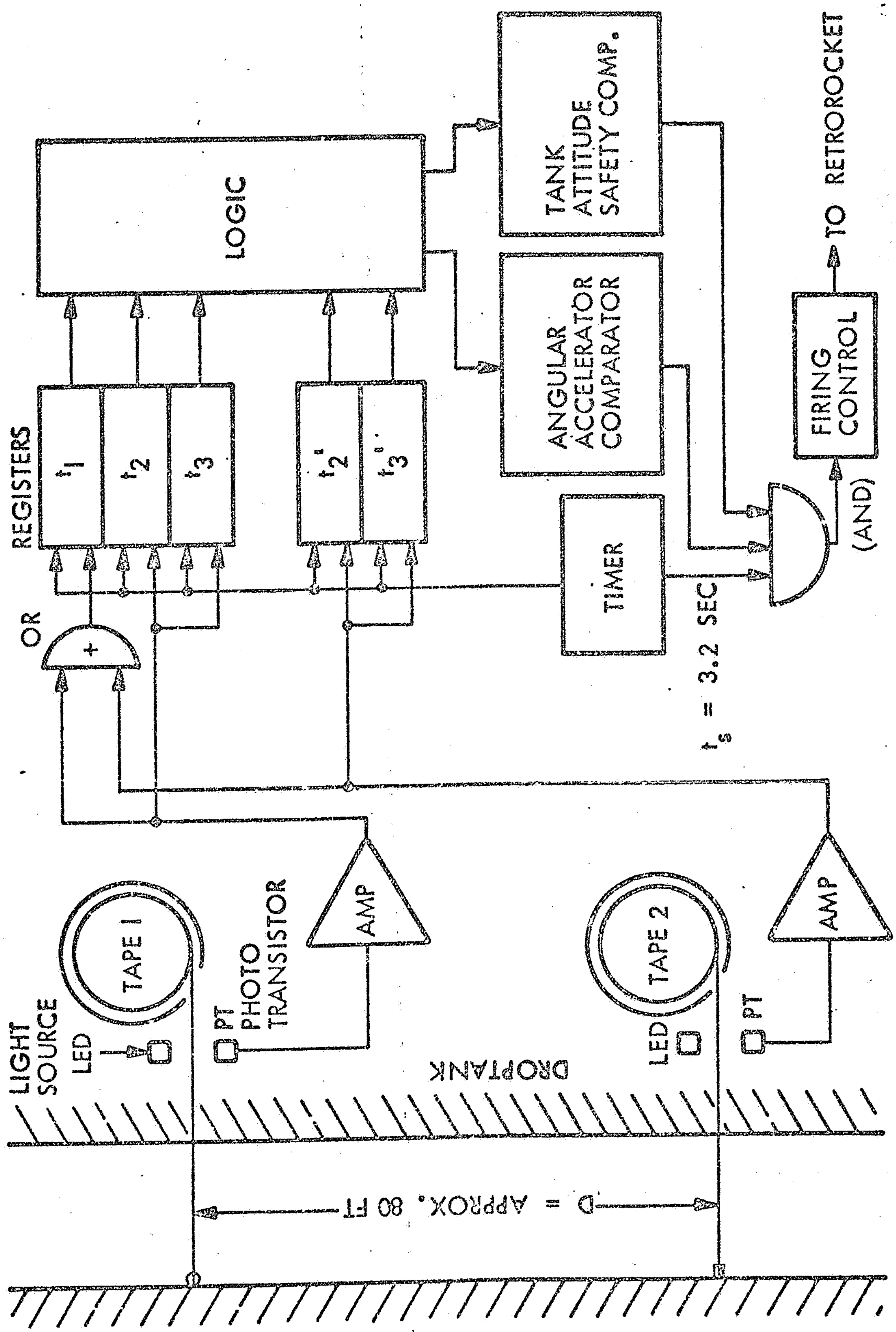

Fig. 13-5 Retrorocket Actuation System

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Fig. 13-5

To preclude the possibility of translation, without angular rotation, causing the droptank to be beyond acceptable attitude limits, which would not be detected by the previous check if one ejection force was delayed but identical in magnitude to the first, a second check is made as follows: (See Fig. 13-5). The tank attitude in the ejection plane is calculated assuming that no angular velocity is occurring.

$$s_2 = s_2' = 10 \text{ ft}$$

$$v_2 = \frac{10}{t_3' - t_1}, \quad v_1 = \frac{10}{t_3 - t_1}$$

For $v_1 > v_2$, and $ds = vdt$

$$\theta ds = v_2 (t_3' - t_3)$$

The second comparator checks that some safety angle θ is not exceeded as a second constraint on the timer firing the retrorocket.

Section 14

MANUFACTURING PLANNING

14.1 INTRODUCTION

Throughout the study phase, Manufacturing interfaced with Design Engineering and Producibility Engineering in developing the design concepts, material selection, and breakdown of the tank elements. The result of this joint effort is a producible, low-cost tank, utilizing current technology and state-of-the-art methodology, machinery, and equipment.

14.2 SCOPE OF EFFORT

As a result of tradeoff studies, and design and producibility analysis, Manufacturing performed a production analysis and cost on the three candidate concepts. The groundrules established for the manufacturing effort were as follows:

- Production of 450 sets of tanks
- Fabrication and assembly to be conducted in a government-furnished facility located at the Kennedy Space Flight Center
- Engineering design freeze for Class II changes established on Set No. 44

Manufacturing's planning and cost scope of effort consisted of the fabrication, assembly, and test of a fully instrumented tank. The thermal insulation was applied, and the tank pressurized and installed under tension on a ground handling dolly ready for logistics stores and subsequent mating with the orbiter vehicles. Included with these costs were the planning documentation, material and process specifications, test procedures, tooling, test equipment and associated services and support for the ten-year production effort.

14.3 MANUFACTURING BREAKDOWN

The structural breakdown is shown in Fig. 14-1. Configuration A is a 2219 T81 aluminum tank, fusion welded. Configuration B is a 2219 T81 aluminum tank, weld-bonded. Configuration C is a 301 extra-hard corrosion-resistant steel tank, fusion, seam, and spot-welded.

The primary differences in the three configurations are in the material and gages, quantity, and length of barrel sections. Configuration A barrels are chem-milled, whereas Configuration B has a doubler framework, and Configuration C is stove-piped with longitudinal doublers.

14.4 PRODUCTION CONCEPTS

The essential differences in the three production concepts are the materials and methods of joining during welding. Fabrication, assembly, and tests of the associated subsystems are basically the same. For example, the nose fairing, retrorocket system, wiring instrumentation, thermal protective system, cleaning and testing were treated alike, with minor exceptions.

The production concept for Configuration A is defined in the following, and only the major difference for Concepts B and C are disclosed.

14.4.1 Production Concept A

Production Concept A is a fusion-welded aluminum tank of 2219 T81, as shown in Fig. 14-2.

14.4.1.1 Fabrication. All machined parts were planned for production on numerically controlled equipment. These included such parts as the nose dome, dome fittings, rings, struts, and manhole covers.

MANUFACTURING BREAKDOWN

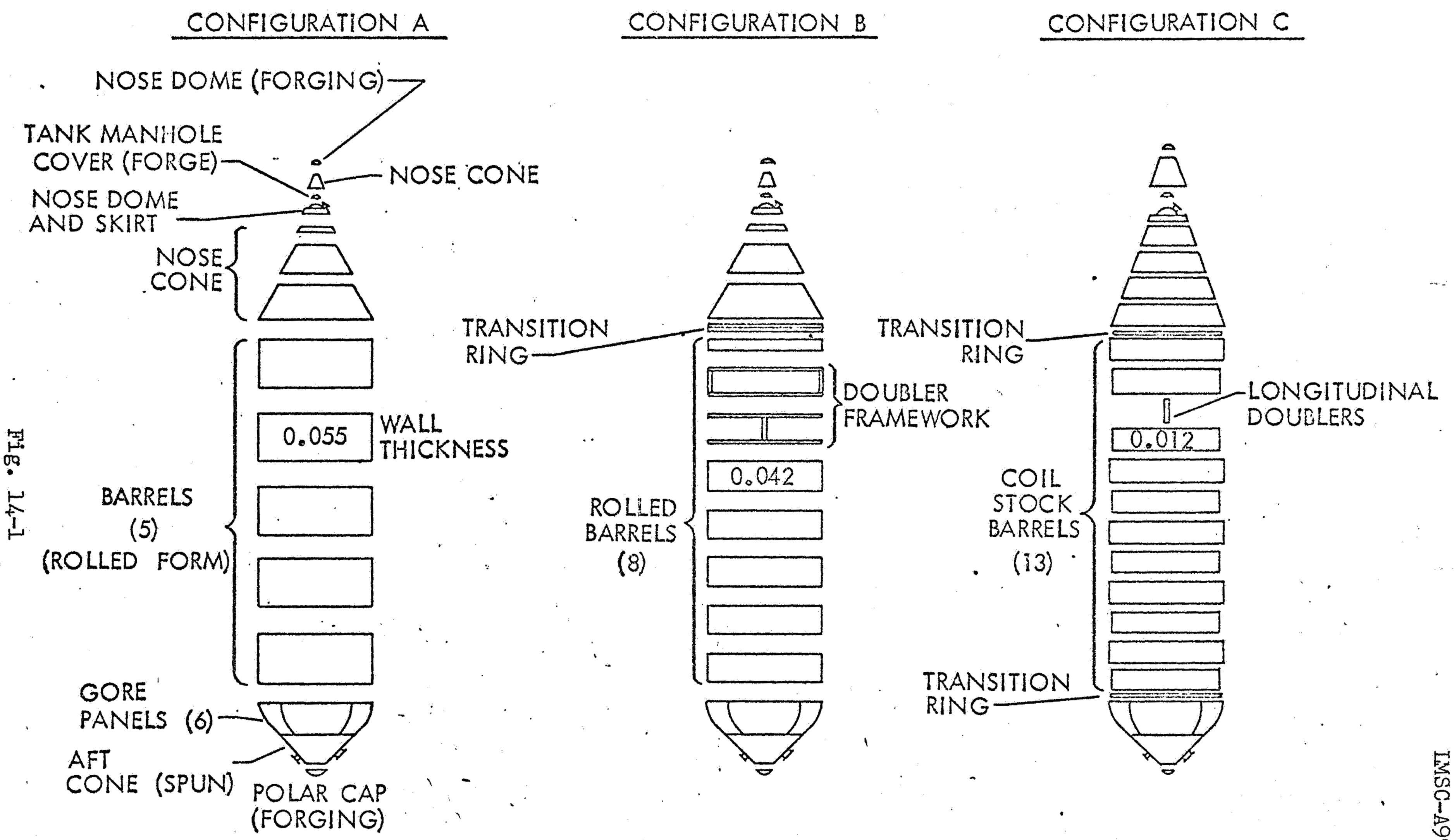

Fig. 14-1

Fig. 14-1

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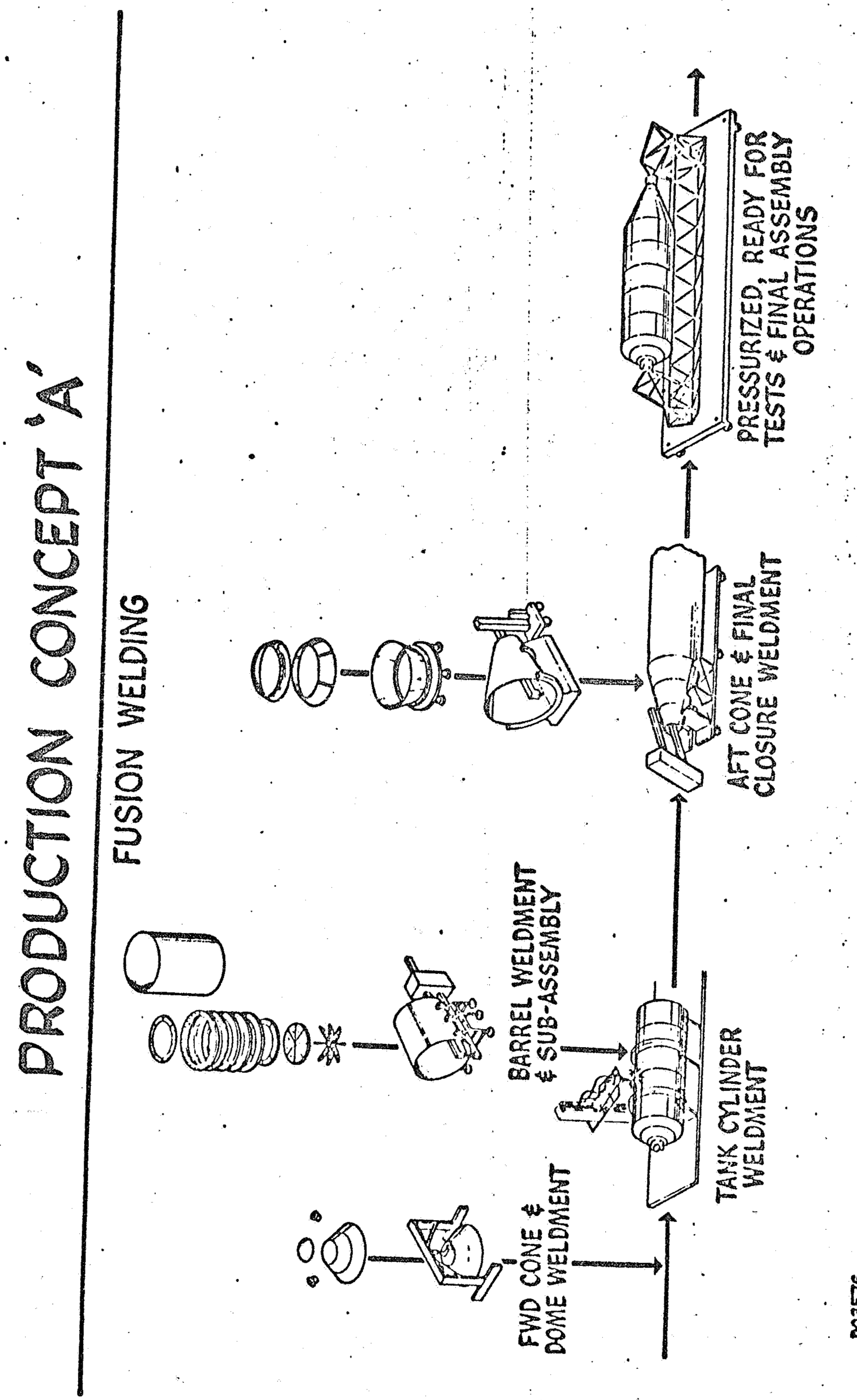


Fig. 14-2

Fig. 14-2

Sheetmetal parts, consisting primarily of the nose shroud components, equipment mounting bracketry, baffles, and clips, will be fabricated by a blanking and forming method.

The gore sections for the domes will be draw-formed, chem-milled, and trimmed for weld-joint interface.

Wire harnesses and black box fabrication will utilize flat cabling to reduce weight and for high reliability.

The large diameter piping (14 in.) is procured in extruded lengths to best accommodate the design requirements. The pipe sections will be machined, trimmed, and electron beam (EB) welded to fittings and bellows. Each joint assembly will be individually pressurized and leak tested prior to the application of polyurethane foam. The full-length pipe assemblies will be proof and leak tested in a fixture providing extension and contraction capability.

14.4.1.2 Weldment Assemblies. The buildup of the tank structure is a series of weldments as shown in Fig. 14-2.

The nose cone segments are longitudinally welded and then mated for circumferential weldment. Cutouts for pipe-outlet fittings are machined, then a final weldment performed of fittings and manhole cover ring.

The barrel sections, consisting of two skins each, are welded longitudinally and trimmed on each end circumferentially. The next operation is to locate and weld internal baffle clips and external piping standoffs. The final operation for each barrel assembly is the installation of baffles and a cleaning preparation for the cylinder weldment assembly.

The tank weldment is a sequential weld buildup joining the aft cone, barrels, and final closure weld at the forward cone.

Upon completion of the final closure weld, all outlets are capped, and the tank is pressurized to 5 psi, mated with a strongback/dolly assembly, and placed in tension as a backup system to pressurization. During all weld operations, Product Assurance's Vidicon and/or x-ray equipment is operating in conjunction with the welder to assure weld integrity of each part.

14.4.1.3 Final Assembly and Tests. The final assembly and test sequences for Concept A are illustrated in Figs. 14-3 and 14-4 and defined as follows:

(1) Proof pressure and leak tests are the first of the final assembly operations. The integrity of the tank is firmly established prior to final cleaning and polyurethane foam application. Proof pressure will be accomplished pneumostatically* at ambient conditions to approximately 33 psig in an inverted position. Leak testing is accomplished at approximately 50 percent of the tank operating pressure, using partial helium. Both proof and leak testing will be accomplished by remote operating equipment.

(2) Internal cleaning will be accomplished in three steps. The first step will be that of acoustical emission; second, an internal wash using freon TF, followed by a purge and drying operation using nitrogen. Cleanliness levels will be remotely monitored by electronic particle counters and laboratory analysis to ensure liquid hydrogen propellant is delivered to the spacecraft interface within the Specification requirements. After cleaning, the tank is then pressurized and monitored throughout the balance of the manufacturing operations.

(3) External cleaning in preparation for the polyurethane foam will be accomplished by hand wiping the surface as required to remove contaminants. The unit is then spray washed with 1,1,1 - Trichlorethane.

(4) Surface preparation involves masking off those surfaces requiring corrosion protection prior to etching, using thixotropic spray and followed by a wash. At this time, the external long run cabling is installed.

*Concept used for costing only.

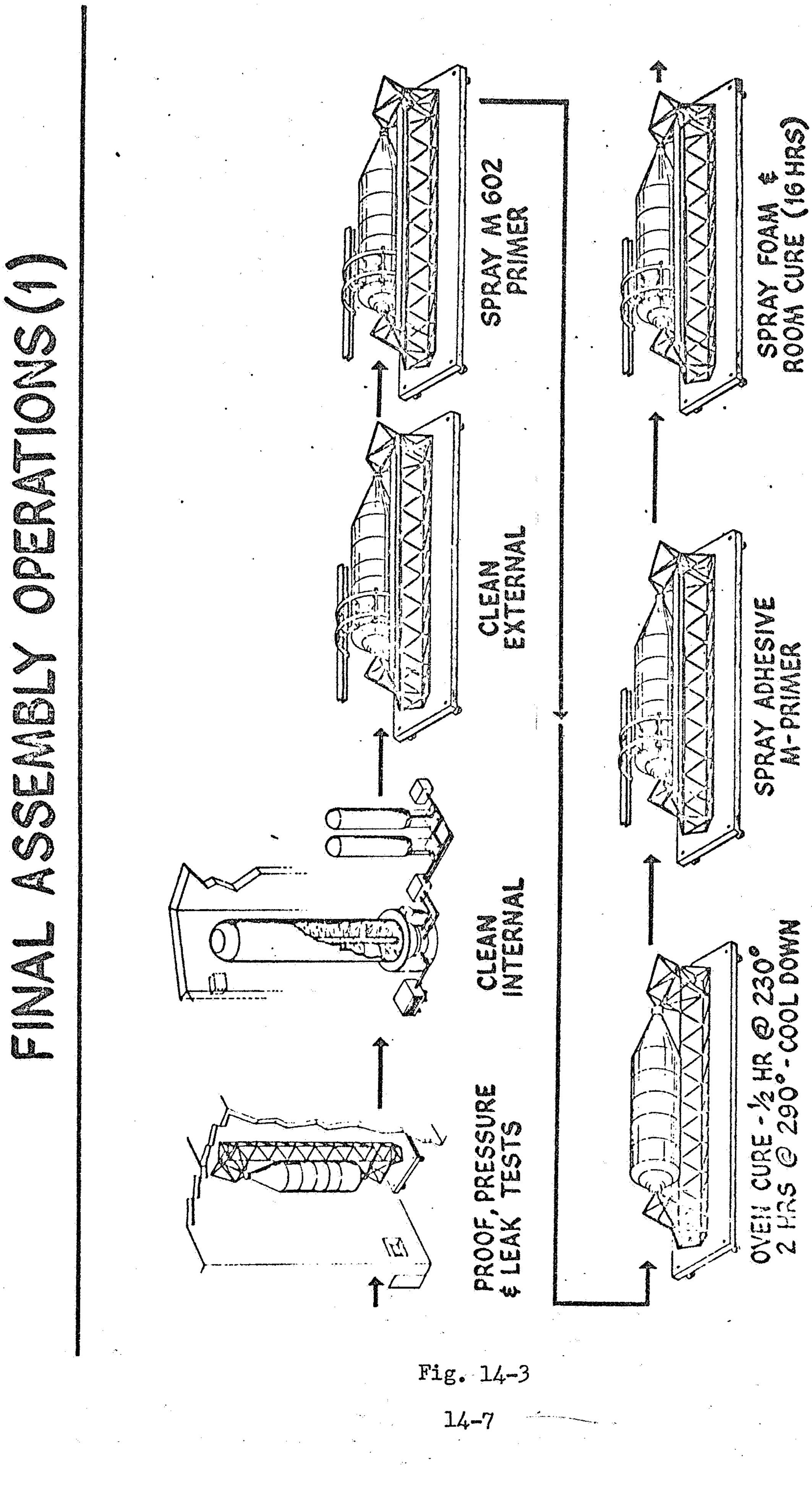
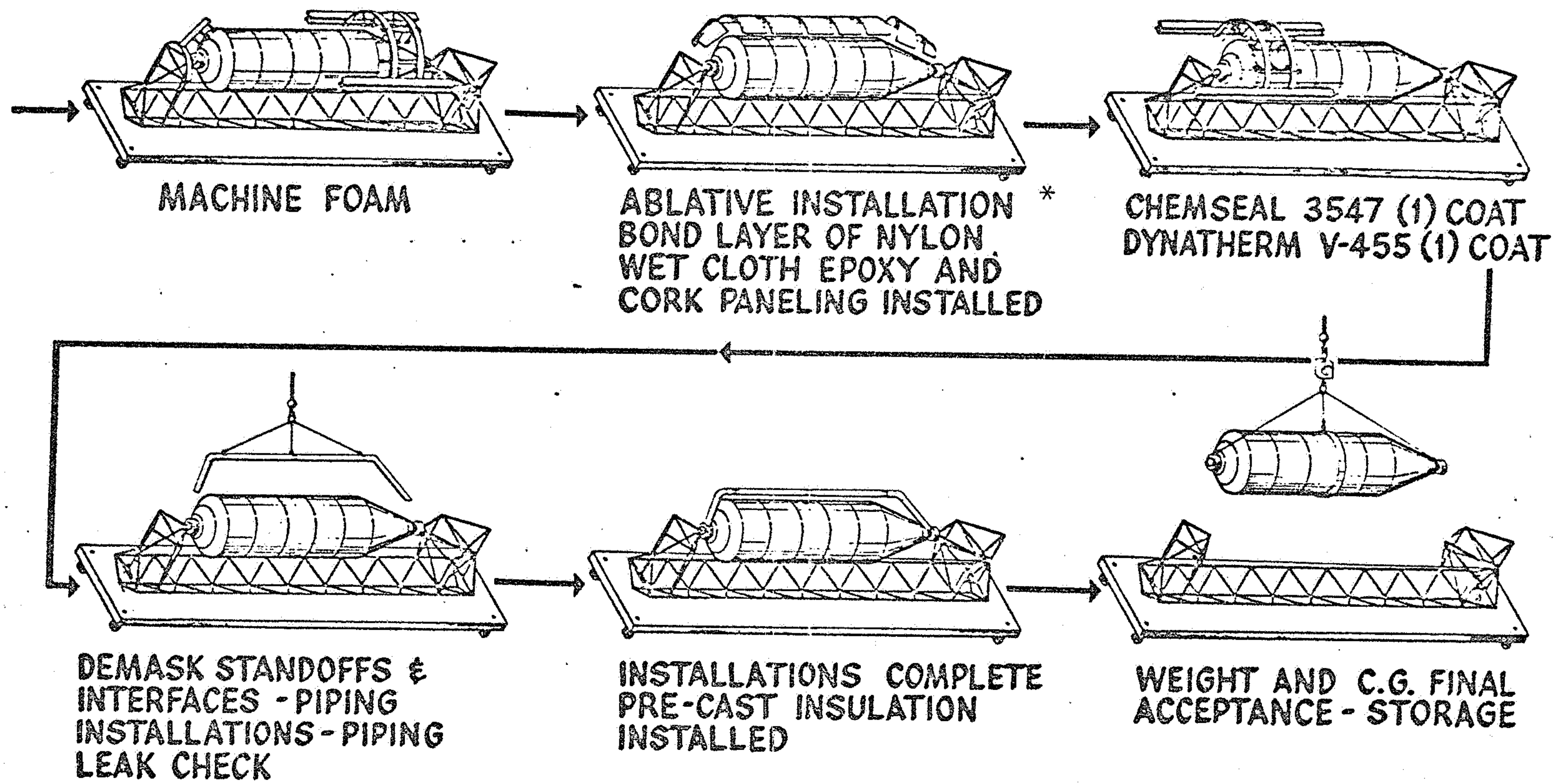


Fig. 14-3

Fig. 14-3

FINAL ASSEMBLY OPERATIONS (2)



14-4

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*Illustrates Application of Insulation for Ascent Protection

Fig.14-4

(5) A seal primer M-602 is then applied by a spray method. Two coats of primer are required and oven cured at 290°F with a controlled cooldown rate.

(6) Spraying of an adhesive M-primer is accomplished using spray guns with remote controls for metering, proportioning, and dispensing the primer. The machinery and equipment for this operation and tank design will require development.

(7) Spray foaming of polyurethane will be accomplished in a temperature- and humidity-controlled facility with numerically controlled equipment. The density, bond, and thickness will be monitored during application by microwave.

(8) Curing of the polyurethane foam will require 16 hours of cure time in a controlled environment.

(9) Machining of the foam is required to achieve minimum weight and for proper installation of the cork ablator. Waviness of the foam showed no appreciable effect on drag. However, Manufacturing considered machining the total area in order to reduce weight and provide cosmetic effects. Machining will be accomplished by multiple heads, numerically programmed to profile for standoffs and sensors to control depth of cut. This system is proposed to be developed during the tank DDT&E phase.

(10) In high heating regions, an ablative material will be applied. This consists of a bond layer of nylon wet-cloth epoxy and cork panels. The cork panels will be precut to size and formed to contour.

(11) The ablative material will be sealed with one coat each of Chemseal-3547 and Dynatherm V-455, sprayed and air-cured.

(12) The next operation is to demask all standoffs and interfaces, ready for hardware installations.

(13) Installations consist of the following equipment:

- Interconnect cabling
- Black boxes and associated bracketry

- Flight instrumentation
- Piping assemblies and associated valving
- Dummy retrorocket and associated mounts
- Fairing, dome and doors

NOTE: Tanks are repressurized after piping is installed.

(14) Final testing is then conducted on all functional systems.

- Leak test at pipe joint interfaces
- Instrumentation - single point readout
- Valving functional test
- Retrorocket alignment
- Pyro circuit verification
- Nose cone matchmate and separation
- Electrical systems check.

(15) Upon completion of installations and tests, precast and formed sections of polyurethane foam and cork are then installed to the balance of exposed areas and joints.

(16) The final operations are the vertical and horizontal weight and center-of-gravity determinations. Upon completion, the dummy retrorocket is removed, and the unit is then ready for final acceptance and transfer to logistics stores.

14.4.2 Production Concept B

Production B Concept is a weld-bonded (spotweld through adhesive bond) design using 2219 T87 material. The assembly breakdown (see Fig. 14-5) is very similar to Concept A. The procedures in this process closely follows those required in conventional resistance welding. The comparative advantages over Concept A fabrication will be shown, followed by a description of the weld buildup technique.

PRODUCTION CONCEPT 'B'

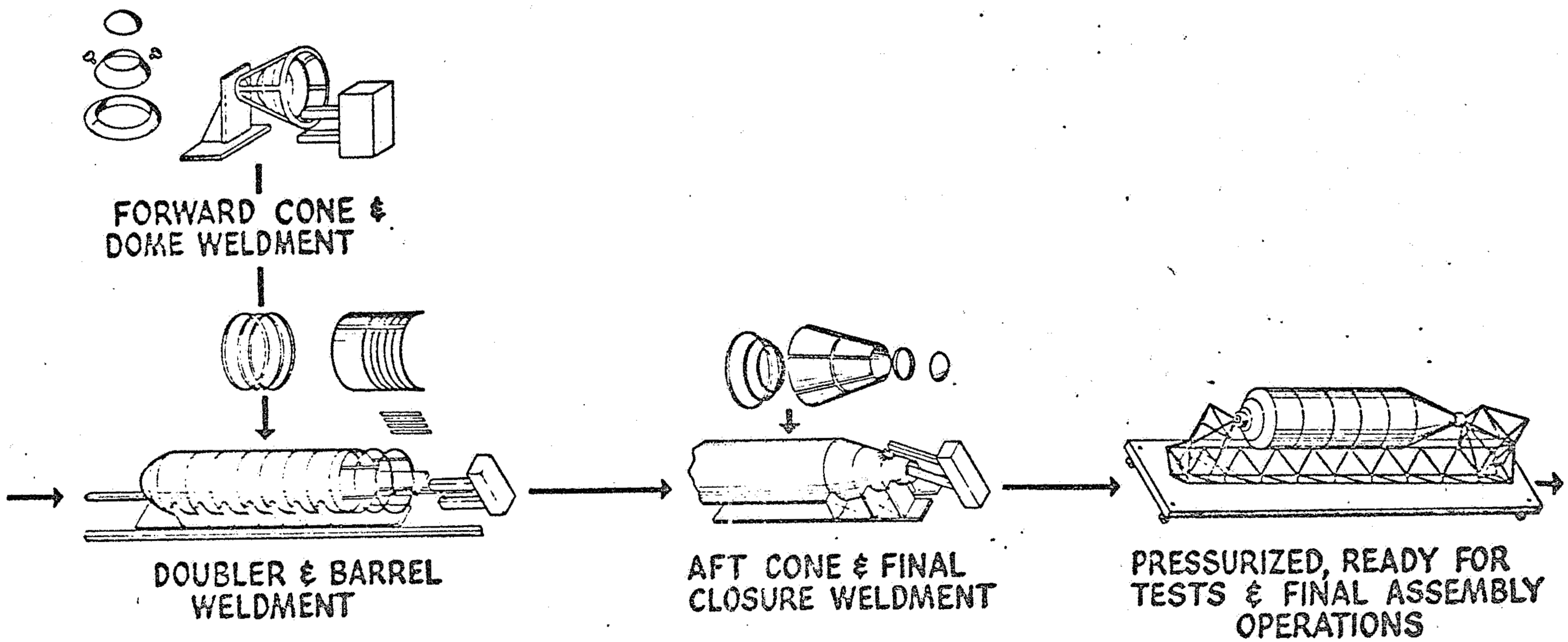

Fig. 14-5

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Fig. 14-5

14.4.2.1 Fabrication. Concept B offers cost advantages over fusion welding as follows:

- Basic sheet thickness is thinner gage, which may be procured with closer tolerances from the mill to reduce weight inasmuch as chem-milling is not required. In fusion welding, a thick gage is necessary due to the weld lands.
- The skins for the dome gores and barrels do not require machine trimmed butt joints, as compared to fusion welding.
- The alignment of skins in the weld operation is not critical.
- The quality of weld in the weld-bond configuration is not critical to stress.

14.4.2.2 Weldment Assembly. The assembly sequence used in the tank buildup is shown in Fig. 14-5.

The spherical cap is a spun dôme with machined and fusion-welded outlet fittings.

The forward cone is built up with a strap subassembly (cage) fusion-welded together at the joint intersection. The straps of the cage form the doublers to which the spherical, conical, or cylindrical segments are weld-bonded.

The EC 2214 adhesive or equivalent can be applied to either the skin or cage assembly. The gap between the skin joints is not critical; however, the overlap between the skin panels and doublers must be maintained. The control of basic dimensions is in the cage assembly.

The doublers and skins are cleaned in the same manner as with conventional resistance welding. Bond curing is to take place within two hours; otherwise thinning of the adhesive is required. Curing will be accomplished in process with fiberglass blankets using heated forced air.

14.4.2.3 Final Assembly and Tests. The final assembly and test operations for Concept B are the same as defined for Concept A (Section 14.4.1.4).

14.4.3 Production Concept C

Production Concept C is built of 301 corrosion-resistance steel, extra-hard condition, and is shown in Fig. 14-6.

14.4.3.1 Fabrication. Fabrication techniques for this concept do not differ appreciably from the other two concepts. The primary difference in this tank is in the weldment assemblies as defined in the following paragraph.

14.4.3.2 Weldment Assembly. The assembly weldment sequence for Configuration C is shown in Fig. 14-6.

The forward and aft spherical caps are machined forgings with machined and welded outlet fittings.

The forward dome gores, which are drawn and trimmed parts, are longitudinally welded and trimmed on each end circumferentially. The conic section is rolled, welded longitudinally and each end is trimmed circumferentially. Both forward and aft domes are then circumferentially welded to complete the subassembly.

The cylinder section consists of 13 barrel weldments; each barrel is approximately 47 in. in length. The barrels are stovepiped (overlap joints) into subassemblies of three barrels each. The weld joint consists of a rolled seam weld at the center lap and spotwelded at the remaining flange area. The same method is used in joining the barrel subassemblies into a cylinder section. The remaining barrel and forward cone form the final closure weld.

All outlets are capped, the tank pressurized to 5 psig, and mated with a strongback/dolly assembly, under tension as backup system to pressurization. The tank structure is then ready for proof pressure tests, cleaning, and final installation.

PRODUCTION CONCEPT 'C'

STAINLESS STEEL

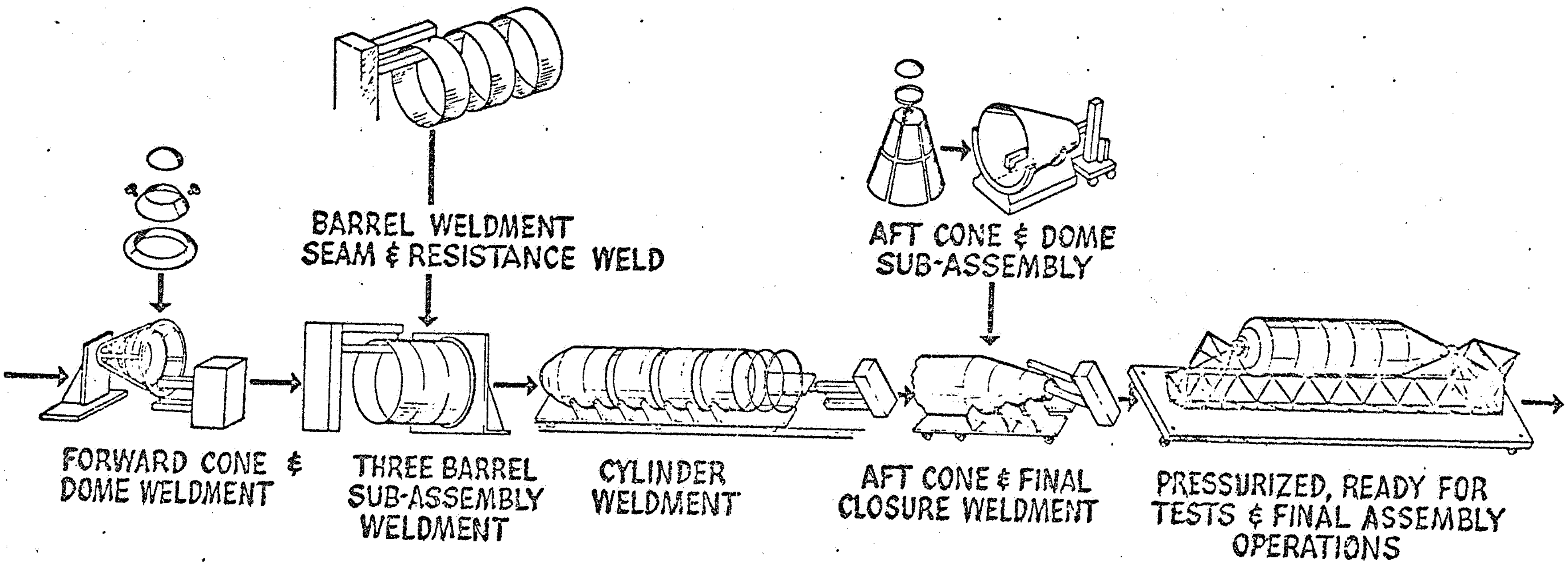

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Fig. 14-6

Fig. 14-6

14.4.3.3 <u>Final Assembly and Tests</u>. The final assembly and test operations for Concept C are the same as for Concept A (Section 14.4.1.3) and shown in Figs. 14-3 and 14-4.

14.5 TOOLING

The philosophy used in planning the tooling requirements include high usage of automation through numerical control, peak rate considerations, optimum utilization, low maintainability, and tool utilization as an in-process inspection medium.

14.5.1 DDT&E Tooling

During the DDT&E phase, limited durable tools consistent with design and program requirements will be provided. Major tools will be designed and constructed so that they will support the development phase at minimum cost. Through modifications and additions, these tools will also be used to support the production phase.

14.5.2 Production Tooling

Numerical control equipment, tooling, and techniques will be used to the maximum extent to reduce tooling fabrication and parts costs, and to maintain part quality. Experience has proved that the reliability of dimensional tolerances is adequately maintained by numerical control and precludes the necessity for an expensive master tooling program.

Assembly tooling will be designed to accommodate the individual requirements of the machine, maximum utilization, and minimum handling.

Consideration for utilization of existing welding equipment established the incremental horizontal tank welding concept.

In Concept A, the fusion-welded tank, longitudinal welds are made using existing state-of-the-art stake welding equipment and MIG weld manipulators. Similar weld manipulators would be used for the circumferential fusion-welding.

In Concept B, the weld-bonded tank, longitudinal and circumferential welds are made with the same pieces of equipment. Multiple, removable spotwelding heads or rolls have been considered and are presently under investigation.

Concept C utilizes both spotwelding and fusion-welding equipment. Fusion-welding is used for the barrel longitudinal joints, which are rolled and spot-resistance welded at the circumferential stovepipe joints. Tooling positions the barrel to the weld axis, rotates the barrels, and pneumatic rings hold the tank diameter.

The strongback/handling dolly is designed to accommodate vertical and horizontal operations for cleaning, testing, and all final assembly operations. By rotational capability and indexing, this piece of equipment is utilized through all of the polyurethane spray and machining operations. Upon tank final acceptance, the strongback travels with the tank through the logistics stores until the tank is mated with the ground handling installation fixtures. The unit is then recycled for use in manufacturing.

The tooling requirements for Concepts A, B, and C are shown in summary form in Table 14-1. The quantities shown were based upon a peak rate of 65 sets of tanks per year. The requirements were determined through an analysis of assembly breakdown and span times based upon two work shifts and learning curve considerations.

Table 14-1

PRIMARY PRODUCTION TOOLS
(1 Set)

PART NOMENCLATURE	CONCEPT 'A'		CONCEPT 'B'		CONCEPT 'C'	
	QTY	MANHRS	QTY	MANHRS	QTY	MANHRS
Nose Fairing	72	13,289	72	13,289	72	13,289
Retro Rocket	77	5,666	77	5,666	77	5,666
Fwd Tank Section	38	22,096	51	17,140	59	26,820
Barrels Sections	10	5,312	13	9,301	18	26,576
Aft Tank Section	31	16,260	39	22,146	36	37,198
Tank Assembly	5	34,876	8	54,540	4	45,792
Plumbing	4	7,733	4	7,733	4	7,733
Thermal	40	48,500	40	48,500	40	48,500
Processing	2	16,020	2	16,020	2	16,020
TOTALS	279	169,752	306	194,335	312	227,594

Table 14-1

14.6 MANUFACTURING TESTING

The objective of the production testing is to provide the maximum amount of correlated data to determine conformance to design or specifications as a basis for acceptance, thereby establishing the highest degree of confidence in the performance of the LH_2 tank.

14.6.1 Test Objectives

The Production Test Program will encompass in-process tests and manufacturing acceptance tests. In-process tests are those production tests performed at intermediate points between receiving tests and start of final manufacturing checkout. They are performed at points of assembly where further assembly will reduce capability of a complete functional test of a specific unit or piece of hardware. Manufacturing acceptance tests are those tests performed for the purpose of verification and assurance that the hardware was manufactured in accordance with design drawings and specifications.

Acceptance tests will be sequenced in such a manner as to preclude duplication of previous testing. During the manufacturing operations, the line-flow testing philosophy will be applied. Component, subassembly, final assembly testing will be accomplished, where applicable, to assure integrity and system operation of the deliverable tank assembly.

14.6.1.1 Test Level Definition

Component levels are defined as those singular parts or assemblies that have a singular identity; i.e., shutoff valves, wire harnesses, circuit boards, tank closure plates, etc.

Subassembly levels are defined as those groups of parts or assemblies installed as a major assembly or module; i.e., total vehicle plumbing assembly, cable assemblies, strut assemblies, etc.

Final assembly level is defined as the tank top assembly level, with all systems installed and operative, less pyros; these include pressure leak tests, instrumentation, alignments, pyro harnessing, and nose dome separation and match/mate separation test.

The tests to be performed are shown in the following Table 14-2.

Table 14-2

Production Testing

	Hi-pot	Continuity	Circuitry	Function	Readout	Clean	Proof Test	Leak Test	Alignment	Match/Mate	Integrity/cg
COMPONENTS											
Harnesses	X	X									
Sequence Timer		X	X	X							
Att. Logic Box		X	X	X							
Tape Sensor Unit		X	X	X							
Closure Plates						X	X	X			
Piping						X	X	X			
SUBASSEMBLIES											
Piping Assemblies						X	X	X			
Tank Structure						X	X	X	X		
FINAL ASSEMBLY											
Piping Joint								X			
Instrumentation					X						
Valving				X							
Retrorocket									X		
Pyro Circuitry					X						
Nose Cone					X					X	
Electrical Sys.					X						
Tank Complete											X

NOTE: An assumption is made that the following listed components are procured and tested at the vendor or upon receipt at Receiving Inspection:

Bellows Assemblies
Piping Flange Assemblies
Pyros
Retrorocket Assemblies
Transducers
Instrumentation Pickups
Propellant System, Valve Assemblies
Batteries

14.6.2 Test Equipment

Tradeoffs such as the fundamental relationship between test equipment maintainability and reliability must be studied analytically. Recurring costs must be considered together with the initial investment figures to derive full visualization of ultimate costs.

The manufacturing approach to production testing requires that the total relationship between the test equipment and design requirements be thoroughly examined. There are four basic interfaces to be considered in designing the following equipment:

(1) Design limits
(2) Test equipment input
(3) Test interface
(4) Test equipment output

14.6.3 Equipment Requirements

Component Testing

- Pressure Source and Test Adapters
- Leak Check Equipment
- Electronic Test Equipment
- Multiplexer Test Adapters

- Test Adapters
- Circuit Analyzer
- Wire Harness Adapter
- Cables
- Pyro/Instr. J-Box Test Adapters
- Sequence Timer Test Adapters
- Power and Power Dist. J-Box Test Adapters

Subassemblies and Final

- Black Light Source
- Storage Pressure Monitor Tool
- Cleaning Equipment
- Freon Reservoir
- Piping System Test Jig
- Piping System Blank-Off
- Flanges and Test Instrumentation
- Piping System Cleaning Equipment
- Optical Alignment Verification
- Air/Helium Pressurization Source
- Test Instrumentation System
- Flange Blank-Off Plates
- Tank Test Closure Plate
- Ultrasonic Leak Detectors
- Mass Spectrometer, He Detector
- Mass Spectrometer Vacuum Source

14.7 PACKAGE AND HANDLING

Packaging Engineering has assessed the requirements for transporting the test tanks to the Test Facilities for the DDT&E Phase.

A total of six test tanks will be prepared for shipment from the Kennedy Space Flight Center (KSC). Four tanks will be shipped to the Marshall Space Flight Center (MSFC), and two to the Mississippi Test Facility (MTF).

Each tank will be intact with a strongback attached and the tank in tension and pressurized. The tank will have a protective cover to prevent damage and control the tank environment during transportation. An auxiliary pressurization system will be provided.

The method of transportation considered was single shipment by barge. Due to schedule requirements, multiple shipment was disallowed. Air transportation was assessed and considered too costly. However, schedule considerations and in-transit time may dictate the necessity for shipment by air. In-transit times by barge from KSC to MSFC and MTF are 7 and 12 days, respectively.

Packaging, handling and transportation of materials for the production phase is relatively low considering it is less than 0.04 percent of the manufacturing costs. The primary items of shipment were as follows:

> In all three concepts (A, B, and C), piping was considered a subcontract item procured from the Parsons Company of Travis, Michigan, and transported by truck to KSC.
>
> The method of transporting the dome forgings was also considered common to the three designs: they were shipped to KSC from Somersville, Massachusetts, by truck.

14.8 TANK GROUND HANDLING

The droptanks are received from the manufacturing final assembly and positioned to a transport dolly, pressurized, and held in tension in the manufacturing strongback structure. The tank is transported to logistics storage in the horizontal attitude. The tanks are tilted to the vertical on the transport dolly and placed on a rail or truck system for sequential storage. They are stored under tension in their manufacturing support structures, pressurized to 3 to 5 psi, with a suitable monitoring and alarm system. After storage, the manufacturing strongbacks are then recycled for use.

When required for use, the tanks are removed from storage in the same sequence they entered. When removed from storage, a tank is placed on a transport dolly and tilted to the horizontal attitude. This transport dolly design incorporates impact recording and ancillary pressurization capabilities.

The transport dolly will be utilized to transfer the tank to the mating area unless the crane rail can be utilized to perform the operation.

Mating of the tanks to the orbiter will be accomplished by use of a ground handling fixture which will be designed to perform the task both horizontally or vertically, as shown in Fig. 14-7. Transfer of the tank to the ground handling fixture is made possible by the use of different attach points. The manufacturing fixture is secured to the flight fittings on the tank caps, while the ground handling fixture attaches to special lugs provided for it. Once secured in the ground handling fixture, the tank is hoisted either horizontally or vertically, and with the flight attach interfaces freed, the tank is secured to the orbiter vehicle. The ground handling fixture is designed to perform its lifting and mating function as well as to provide the required longitudinal tension to protect the tank should there be a loss of pressure during handling operations.

Tilting capability is not built into handling equipment, since it already exists in the manufacturing dolly. However, to permit hoisting in either attitude, two different-length cable slings will be required and equipped with a built-in capability to compensate for center-of-gravity shifts and permit level hoisting. Additionally, a vertical micropositioning device will be required between the sling and the overhead hoist to permit precise vertical adjustments during mating.

The following equipment is required for tank ground handling:

- Transport dolly - equipped with "G" impact recorders, ancillary pressure supply, and strongbacks
- Hoisting and mating fixture
- Vertical hoisting sling
- Horizontal hoisting sling
- Micropositioning device

LOCKHEED

TANK GROUND HANDLING

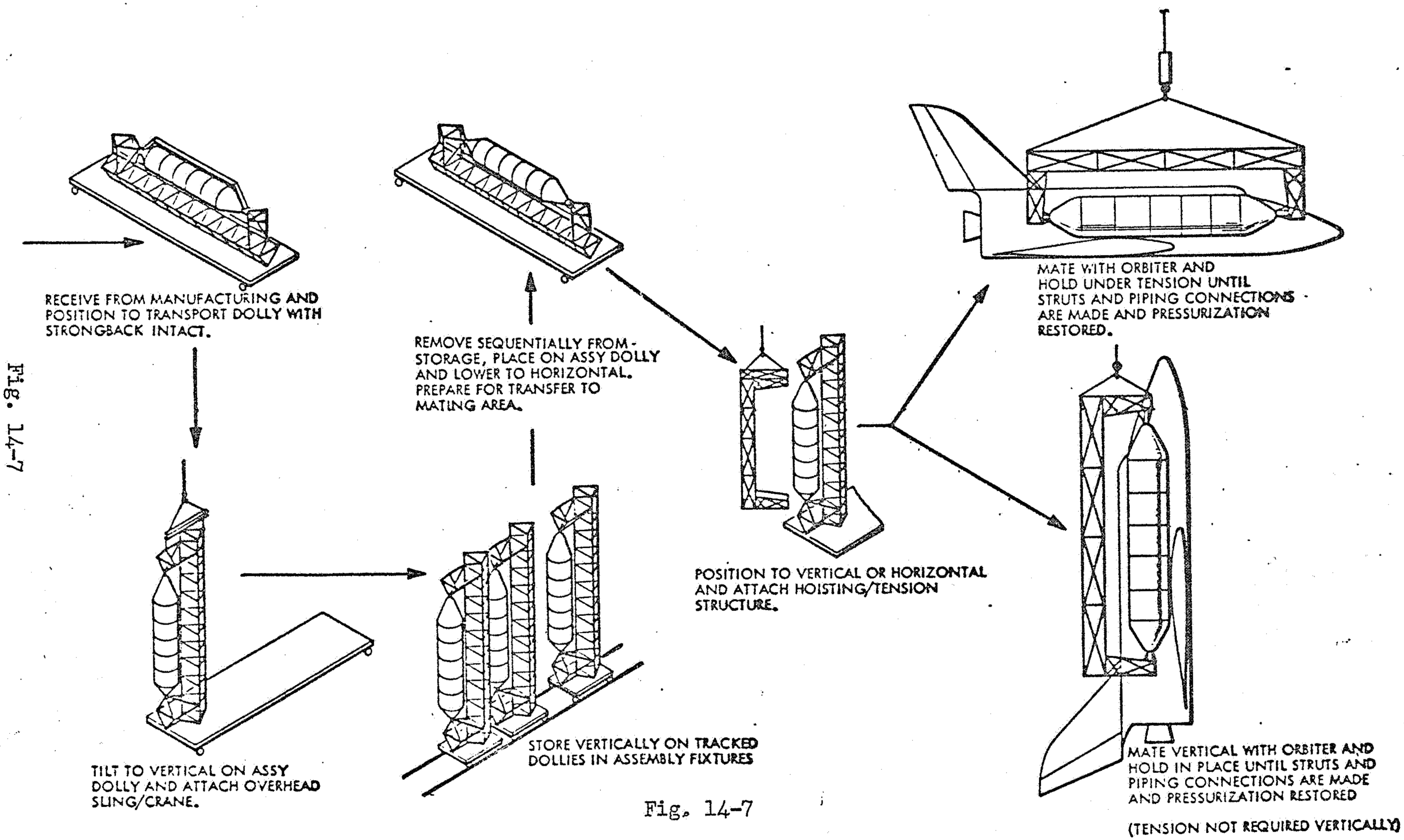

Fig. 14-7

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Fig. 14-7

14.9 LOGISTICS/STORAGE

This plan is applicable to droptanks, either accepted by NASA and waiting for delivery to the orbiter vehicle/droptank mating operation or upon completion of manufacture and acceptance test and waiting for delivery to the orbiter vehicle/droptank mating operation.

Logistics and Material Operations will receive and assume custody of the droptanks and kits consisting of struts and pyro devices upon completion and final acceptance. The storage site selected is the low bay of the KSC VAB building, as shown in Fig. 14-8. Scheduling of droptanks into and out of storage is on a first-in first-out basis in accordance with the Space Shuttle Master Schedule. Maximum storage life assumed is one year.

Space Shuttle droptanks will be delivered to the storage building pressurized and prepared for storage in accordance with a storage specification.

Related documentation received with the droptanks will include the Droptank Storage Log Book (DTSLB) which, verified by Product Assurance, will reflect the actual physical condition of the droptank and other data pertinent to the storage activity.

Present information indicates that storage building floor space limitations, based on the vehicle assembly building lower bay area, preclude storage of more than 39 tanks in a vertical position. Since the present schedule indicates a need for storage of a maximum of 70 tanks in the same time period, recommendations of scheduling to alleviate this condition are discussed in the program management section.

Refurbishments, minor modifications, and repairs can be accomplished within the storage area by manufacturing personnel. Logistics management pertaining to limited calendar-life items and associated logistics management will require additional study.

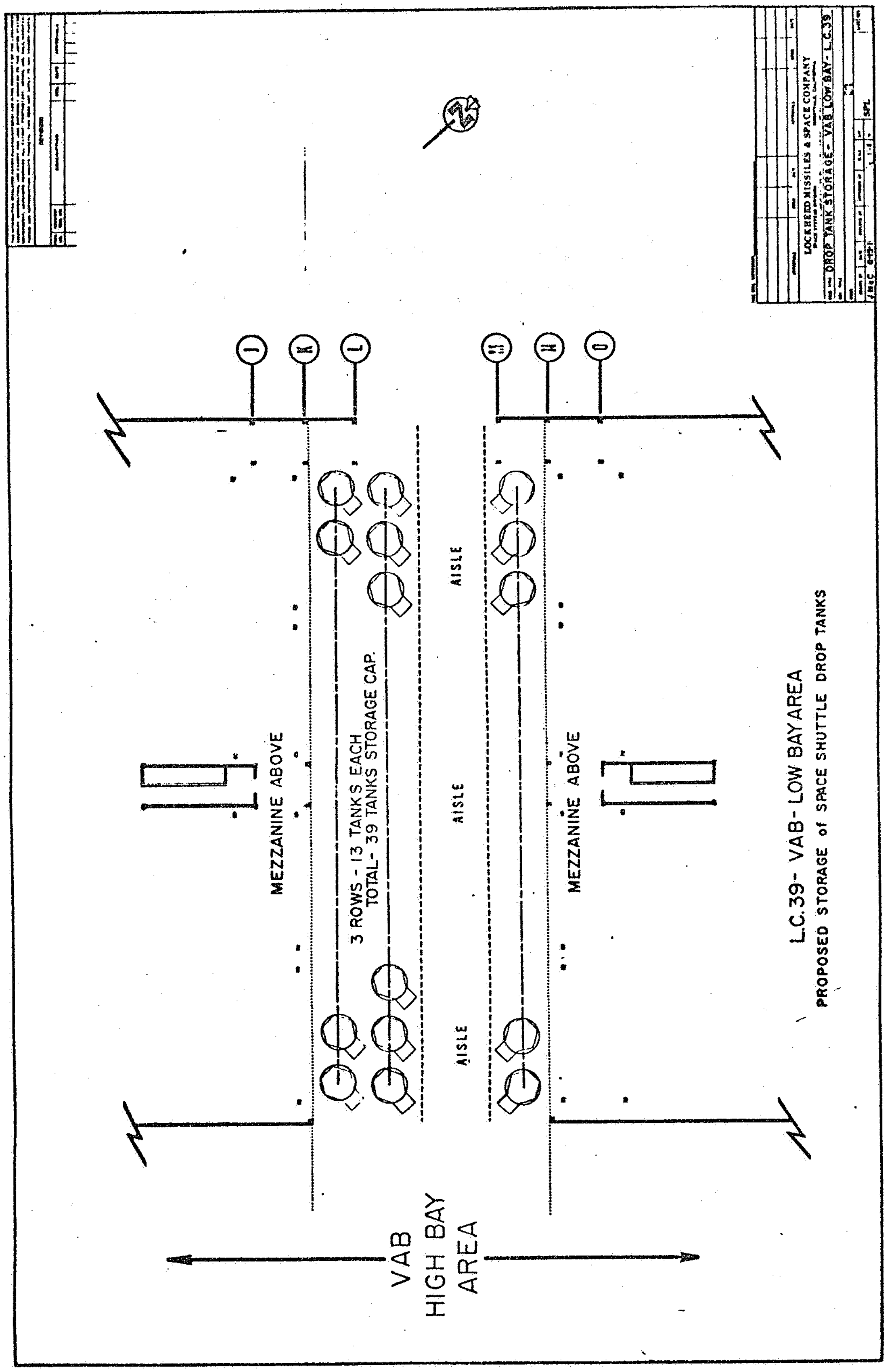


Fig. 14-8 VAB Low Bay Area

Fig. 14-8

14.10 EQUIPMENT AND FACILITIES

The machinery and equipment requirements were determined by a rough order-of-magnitude, and the costs in gross figures are shown on Table 14-4. Specially designed equipment to meet tank production requirements needs to be developed, especially in the area of thermal application. Spray equipment and numerically controlled sensing heads for machining of polyurethane foam are of prime concern. The equipment currently available on the market is not considered adequate. Additional equipment studies should be conducted in conjunction with industrial equipment designers upon firm design disclosure.

In planning the manufacturing requirement for the LH_2 tanks, an existing manufacturing facility was assumed as available at KSC to meet the needs of production. However, for planning purposes, the area requirements and facilities costs were established as shown in Table 14-3. These requirements were determined for a peak rate of 65 tanks per year. The dollar costs were predicated upon current West Coast construction rates.

14.11 MANUFACTURING COSTS

Manufacturing tank production costs were established by a detailed estimate of the tank systems components, tests, and assembly operations. The estimates were derived in a joint effort with tool and production engineering. The design requirements were established, tooling and test determinations made, sequence of operations established, and equipment requirements ascertained. A buildup of production manhours by piece parts and assembly and test operations resulted in a unit value at a predetermined position on the learning curve. This figure was then projected to a theoretical first-unit value, and then projected on a 92-percent learning curve, for a cumulative total of 450 sets of tanks.

Included in the production costs was a factor for engineering changes and redundancy. The change factor was established at 15 percent of initial hardware

Table 14-3

MANUFACTURING FACILITIES

	A		B		C	
	Area	$ (000)	Area	$ (000)	Area	$ (000)
Acceptance Area	9,500	380	9,500	380	9,500	380
Weight & CG	10,850	542.5	10,850	542.5	10,850	542.5
Misc. Instl.	9,500	285	9,500	284	9,500	284
Plumb. & Hardware	14,200	426	14,200	426	14,200	426
Insulation & TPS:						
Clean & Mark	9,500	380	9,500	380	9,500	380
Spray Etch	9,500	380	9,500	380	9,500	380
Bond Ext. Wrng.	9,500	380	9,500	380	9,500	380
Prime & Cure	28,400	1,136	28,400	1,136	28,400	1,136
Spray Foam & Cure	28,400	1,136	28,400	1,136	28,400	1,136
Machine Foam	28,400	1,136	28,400	1,136	28,400	1,136
Spray Epoxy	28,400	1,136	28,400	1,136	28,400	1,136
Clean & Test	28,400	1,420	28,400	1,420	28,400	1,420
Sub-Assy Test	11,000	440	11,000	440	11,000	440
Tank-Trim, Weld, X-ray	16,000	960	45,000	1,800	45,000	1,800
Elec. Harness	5,000	175	5,000	175	5,000	1,800
Plumbing Weld	7,500	262.5	7,500	262.5	7,500	262.5
Strut-Weld	5,500	175	5,500	175	5,500	175
Aft Dome-Weld	6,400	224	9,400	329	9,400	329
Tank Cone-Weld	6,400	224	9,400	329	9,400	329
Baffle & Screen-Weld	5,000	175	5,000	175	5,000	175
Cone Trans. Skirt	6,400	224	6,400	224	6,400	224
Retro Rocket	2,500	87.5	2,500	87.5	2,500	87.5
Nose Cone Assem.	7,150	250.3	7,150	250.3	7,150	250.3
Nose Cone-Weld	3,250	113.7	3,250	113.7	3,250	113.7
Special Mach. Shop	16,000	480	16,000	480	16,000	480
" Weld Shop	8,000	280	8,000	280	8,000	280
Machine Shop-Gen.	25,000	750	25,000	750	25,000	750
Sheet Metal	25,000	750	20,000	600	20,000	600
Processing	10,000	300	10,000	300	10,000	300
Plumbing Fab.	5,000	175	5,000	150	5,000	150
Inspection-Storage	40,000	1,200	45,000	1,350	45,000	1,350
Prod. Control Cribs	20,000	600	20,000	600	20,000	600
Tool Cribs	5,000	150	5,000	150	5,000	150
Mfg. Desk & Board	10,000	500	10,000	500	10,000	500
Total Area		17,233.5		18,258.5		19,883.5
Total $	$460,650		$495,650		$495,650	

through the 44th set of production tanks. The redundancy factor was based upon 5 percent of total tank production. The applied percentages are based upon historical cost data. The cutoff point for engineering changes is based upon the theoretical point in time when engineering design and production methodology has been firmly established.

A breakdown of nonrecurring and recurring manufacturing costs is shown in Tables 14-4 and 14-5.

14.12 PRODUCTION SCHEDULE

The manufacturing labor and rate tooling considerations were established to the production schedule shown in Fig. 14-9.

LOCKHEED

MANUFACTURING COST SUMMARY (NONRECURRING) DDT&E AND PRODUCTION

	CONFIG. A	CONFIG. B	CONFIG. C
HARDWARE (000 MANHOURS)			
TANK HARDWARE	355.8	313.8	386.6
TOOLING AND TEST EQUIPMENT	644.6	960.1	1,021.0
TOOL AND TEST ENGINEERING	94.1	105.3	119.9
PLANNING AND OPERATIONS ENGINEERING	1,816.0	1,567.0	1,708.1
TOTAL MANHOURS	2,910.5	2,946.2	3,235.6
TRANSPORTATION AND MATERIALS (000)$			
TRANSPORTATION AND PACKAGING	456	456	456
TOOLING AND TEST EQUIPMENT	2,102	2,687	2,820
TOTAL DOLLARS	$ 2,558	$ 3,143	$ 3,276
MACHINERY AND EQUIPMENT (000)$	$ 7,603	$ 8,215	$10,715
LOGISTICS AND GROUND HANDLING (000)$	$ 7,450	$ 7,450	$ 7,450

D03822

Table 14-4

Table 14-4

LOCKHEED

MANUFACTURING COST SUMMARY (RECURRING)
PRODUCTION

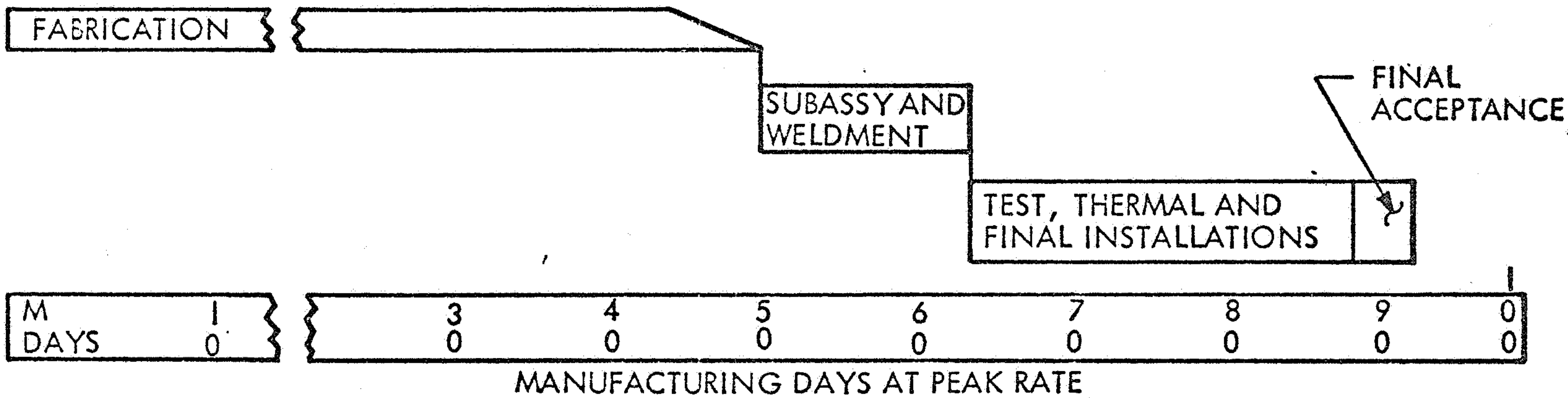
	CONFIG. A	CONFIG. B	CONFIG. C
HARDWARE (000 MANHOURS)			
TANKS (450 SETS)	23,059	19,810	21,693
TOOLING AND TEST EQUIPMENT	111	145	142
TOOLING AND TEST ENGINEERING	83	112	110
PLANNING AND OPERATIONS ENGINEERING	874	686	843
TOTAL MANHOURS	24,127	20,753	22,788
TRANSPORTATION AND MATERIALS (000)$			
TRANSPORTATION AND PACKAGING	2,298	2,298	521
TOOLING AND TEST EQUIPMENT	169	203	212
TOTAL DOLLARS	$2,467	$2,501	$733
LOGISTICS (000 MANHOURS)	36	36	36

Table 14-5

D03821

Table 14-5

MANUFACTURING LH_2 TANK SCHEDULE



TANK PRODUCTION SCHEDULE – FLIGHT DROPTANKS	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
PRODUCTION – SETS	5	15	20	25	30	45	55	65	65	65	60
CUM PRODUCTION – SETS	5	20	40	65	95	140	195	260	325	390	450
FLIGHT USAGE – SETS		10	15	20	30	40	50	60	70	75	75
CUM USAGE – SETS		10	25	45	75	115	165	225	295	370	445
REQ'D STORAGE – SETS	5	10	15	20	20	25	30	35	30	20	5

Fig. 14-9

D03548

Fig. 14-9

Section 15

PRODUCT ASSURANCE CONSIDERATIONS

15.1 INTRODUCTION

In analyzing the three droptank design configurations, the Product Assurance efforts were guided by two factors: acceptable quality and low cost.

This section describes briefly a quality program which can achieve acceptable quality and low cost. The remainder of the section is devoted to describing four major areas of quality participation each of which will have a profound effect on the achievement of the quality goals. These major areas are:

15.2 Production Tooling Considerations
15.3 Weld/Inspection Concepts
15.4 TPS Inspection Concepts
15.5 Acceptance Testing

A quality program which supports the manufacture of any of the three candidate tank configurations (A, B, and C) will have the following features:

- Quality support must start at the beginning of the DDT&E program. Through design coordination, the quality engineer must assist in developing the necessary acceptable quality of the design. Design specifications will be prepared with requirements that establish a quality level consistent with the droptank mission requirements. Typical examples of items which can lower the acceptable quality level and lower the cost of inspection are relaxed tolerances; dimensioning; expressed limits for characteristics like surface smoothness, weld defects, allowable disbonded areas of adhesive, alignment, etc. Additionally, repair procedures, redundancy and cleanliness are other examples where quality will influence the design specifications to include quality inputs to preclude costly misunderstanding later in the program when hardware is involved.

- Production tooling at all levels of tank details, subassemblies and assemblies will be reviewed by Product Assurance to make maximum utilization of the tool as the means for inspecting and accepting tank hardware.

- Manufacturing plans for the candidate tank configurations were evaluated, and "Integrated Planning", which combines the shop order and the inspection instructions into one document, will be used to accept hardware. Substantial savings would be realized for not preparing separate inspection instructions.

- Manufacturing Process Control will be vigorously enforced. Maximum utilization of the process to ensure the quality of the process will reduce the need for extensive subsequent inspection. Tests will be conducted by Product Assurance during the development phase to establish the control criteria.

- Acceptance testing will require Product Assurance approval of the test procedures, proofing of the test station, certification of test personnel, witnessing of all acceptance tests, recording of all discrepancies noted during test and taking appropriate corrective action.

- Material Review/Corrective Action systems will be required to disposition discrepant material, and ensure that corrective action will preclude a recurrence of a similar defect.

- Supplier/Subcontractor quality will be controlled to achieve the same objective as with LMSC's in-house manufacture. Acceptable quality and low cost will guide every quality requirement assessed on any supplier or subcontractor.

15.2 CONTROLLED PRODUCTION TOOLING

Controlled Production Tooling (referred to as Inspection Media Tooling) is a technique in which tools are designed to act as their own criteria for inspection. Tools in this category are designed to maintain the required accuracy over a long life. Product Assurance quality engineers establish the inspection media requirements and perform the design review of the tool design.

All tooling for the fusion-welded or weld-bonded configuration will be designed for maximum utilization as the inspection media. Control factors with the weld-bond concept can be readily established and maintained. Present LMSC experience with the weld-bonded Centaur Standard Shroud has shown the effectiveness of this concept.

There is a direct correlation between the development of acceptable levels of quality for the tank design configurations and the production tooling required for those configurations. The lesser the design requirement, the simpler the tooling.

Final acceptance of controlled tooling is made after the first production piece has been made and the hardware is subjected to a 100 percent inspection. When the hardware passes this inspection, the tool is certified by Product Assurance for production usage. The subsequent level of inspection applied to the hardware varies with each design and each tool, but it is greatly reduced.

Controlled tooling undergoes periodic reinspection and the frequency is affected by many variables, such as wear through normal usage, damage, time factors, etc. The frequency and reinspection requirements are established by Product Assurance.

It can be concluded that the Controlled Tooling technique can be successfully applied to any of the tank design configurations. Further, it can be expected that this technique will result in low inspection costs.

15.3 WELD/INSPECTION CONCEPTS

The quality issue in reviewing the candidate tank design configurations was "what weld inspection techniques are available or in development, and what is the advantage/disadvantage of each." The following information describes the findings to date for each of the candidate tank configurations.

15.3.1 Design Concept A, Fusion-Welded Aluminum (2219 T-81)

Typical candidate inspection concepts for fusion-welding are as follows:

Inspection Concept	Advantage	Disadvantage
Radioactive source	Readily available Low installation costs Low maintenance costs	Hazardous Area isolation
X-Ray source	Readily available Less Hazardous than radioactive source	Higher installation costs and higher maintenance costs than radioactive source
Vidicon X-Ray	Real-time inspection Low inspection time Readily available	Low definition High equipment costs
Acoustic emissions	Real-time inspection Low equipment costs	Development costs

The conclusions reached for Design Concept A were that it had the smallest amount of welding and the least amount of joints to affect the pressure integrity of the tank. Most of the equipment for the above concept was available and the estimated equipment costs were the lowest. Therefore, it was concluded that from a welding viewpoint Concept A was the most desirable. The choice of which inspection concept is the best will be made from economic evaluations of each system -- the system which can verify and ensure the attainment of acceptable weld quality at the lowest overall program costs will be selected. This method of selecting the inspection concept applies to the next two design configurations as well.

15.3.2 Design Concept B, Weld-Bonded Aluminum (2219 T-87)

Typical candidate inspection concepts for weld-bonding are as follows:

Inspection Concept	Advantage	Disadvantage
Pulse echo-water-coupled	Low inspection time Readily available Inspects spotwelds and adhesive bonding Access to one side	High equipment costs
Low-frequency Ultra sound-air-coupled	Low inspection time Readily available No fluids involved	High equipment costs Need access to two sides
Ultrasonic crystals	Real-time inspection Low equipment costs	Spotweld inspection only - additional infrared scanner required
TV in-motion radiography	Real-time inspection Inspects spotwelds and adhesive bonding	High equipment costs Needs development
Pulsed laser holography	Rapid inspection on large areas	Needs development

The conclusions reached for Design Concept B were that it had the lowest overall quality costs, but while some of the candidate inspection equipment was available, other equipment required extensive development programs. Additionally, from the LMSC experience gained in weld-bonding the Centaur Standard Shroud, Product Assurance feels that weld-bonded LH_2 tanks have the greatest potential for lowest inspection cost.

Weld-bonding is a mature manufacturing process which joins metals by spotwelding through an adhesive bond. By combining the best features of spotwelding and adhesive bonding, low-cost spotwelds that act as a holding fixture are obtained. These eliminate costly tooling for the bonding process. The high joint strength of the adhesive bonding also overcomes the low fatigue strength of spotwelds.

A quality development program must be conducted to verify the capability of the candidate inspection concepts. Repair/rework procedures will be required when discrepant spotwelds or voids in the adhesive bonding are detected. Process control will directly affect the inspection concepts, since the degree of defect potential will dictate the sophistication of the inspection equipment.

15.3.3 Design Concept C, Spot & Fusion-Welded Stainless Steel (Type 301 - Extra Hard)

Typical candidate inspection concepts for spotwelds only are as follows; the fusion-welding concepts would be the same as for Design Concept A.

Inspection Concept	Advantage	Disadvantage
Ultrasonic search wheel	Low equipment cost - readily available	High inspection time - fluid couplant
Pulse echo	Low inspection time readily available	High equipment costs - fluid couplant
Ultrasonic crystals	Real-time inspection	Requires rod anodes - needs development

The conclusions reached for Design Concept C were that it contained the most welding, had the most joints, had the thinnest wall sections, therefore requiring extra handling and tooling capabilities to preclude damaging the tanks. Inspection equipment is generally available and would only require adaptation to the Lockheed design and manufacturing technique. From a welding viewpoint, this concept was the least attractive.

15.4 TPS INSPECTION CONCEPTS

Product Assurance has investigated the inspection techniques capable of verifying the acceptable quality requirements for the proposed ablator and cellular foam insulation.

15.4.1 Cryogenic Insulation

The low density (2.0 lb/ft^3) of the foam will require that Product Assurance conduct tests to develop acceptance techniques using either rigid process controls, or nondestructive test such as radio-microwave, Eddy current, RF energy or a combination of these.

Results of our investigations thus far indicate that acceptance of the process of applying the foam insulation will best be accomplished through rigid control of the process. Careful selection of equipment, environmental control of work areas, training and certification of the operators and inspectors, and establishment of process control limits that meet or exceed the acceptable quality specifications are required.

15.4.2 Ablator Materials

Radio microwave scanning of the ablator material will give rapid real-time verification of the density, thickness, and bonding characteristics. Disbonds or voids (1/4 sq in. or larger) can be readily detected and recorded on tape to expedite rapid repair as required. Quality requirements invoked on Lockheed suppliers of ablator materials will assure the shipment of material which meets the acceptable quality requirements. This effort will reduce the amount of subsequent inspection that must be performed on the ablator materials during or after installation onto the tanks.

15.4.3 Other Considerations and Problems

Repair or rework techniques developed for the droptank TPS systems will be partially responsible for determining when the acceptance verifications will take place. For example, it may be possible to reduce inspection time by scanning the tank assembly with microwaves after it has been completely insulated. Such parameters as adhesive disbonds, voids, and coating thickness could be verified; however, repairs or rework at this point may not be practical. Studies are required to examine the various tradeoffs and to make decisions which will provide acceptable quality at lowest cost.

Product Assurance will assist in the development of the insulation quality levels and particular emphasis will be centered on aluminum corrosion. Selection of primers, determination of surface conditions to provide continuous coverage, curing and work area ambient conditions are typical factors which will be considered to eliminate the possibility of corrosion.

The proposed manufacturing plan to build a complete tank before applying the primers will enhance the chances of coating the entire surface with a heat-cured primer; this will decrease the potential for corrosion.

15.5 ACCEPTANCE TESTING

During the droptank manufacturing sequence, a line-flow testing philosophy will be used. Component, subassembly, and final assembly testing will be performed where applicable and, as a minimum, Product Assurance will control all acceptance testing in the following manner.

- Review and approval of Test Plans and Acceptance Test Procedures for Lockheed and supplier-performed acceptance testing, to ensure test level conforms to Design Specification requirements.

- Certify Lockheed and supplier test stations and test personnel to ascertain readiness for test. Review and approve (if applicable) Equipment Test Procedures.

- Witness all acceptance tests.

- Record all discrepancies found during test and direct corrective action decisions to rectify the known discrepancy and to preclude its recurrence.

- Assist in developing test data requirements to be taken during test. This data will be essential to producing objective evidence that sample testing of production tanks is in order after a certain confidence level has been achieved.

- Upon the successful completion of acceptance testing, clearly indicate the quality acceptance on the hardware as well as the supporting documentation.

15.5.1 Safety Considerations

During all phases of acceptance testing, safety of test personnel and the inability to damage the hardware will be major quality objectives. Each test procedure and test station will be evaluated for its inherent safety characteristics.

15.5.2 Components & Subassembly Level Testing

Analysis of the components and subassemblies which require test indicate no major problems for Product Assurance during hardware acceptance. One area of concern is to control cleanliness all through the component and subassembly build-up to minimize the difficulty of the final tank cleaning. Further cost studies are necessary to ascertain the cost tradeoffs for controlling cleanliness and packaging at this level versus doing it all at the tank complete level.

15.5.3 Final Assembly Level Testing

15.5.3.1 Proof Pressure & Leak Test will determine the integrity of the tank as a pressure vessel and the validity of the piping joint interfaces at tank flanges. Further development work will be required to utilize Acoustic Emissions as the means to detect incipient failures in pressure vessels by stress-wave emissions. LMSC studies show that such a system would provide data to show the onset of flaw growth, the location of the crack, the rate at which it was growing and the degree of risk associated with the flaw. Product Assurance considers this technique as a contributor to reduced inspection which would assist in developing confidence in the welding process.

15.5.3.2 Tank Cleaning (Internal) will be controlled by data received from in-line electronic particle counters which are analyzing the flushed out liquid freon with additional data received from microscopic examination of laboratory samples. It is also anticipated that a visual black-light examination might be necessary to meet contamination specifications.

15.5.3.3 Tank Handling and Storage. Recognizing the vulnerability of thin-walled tanks, Product Assurance is concerned with improper handling which might damage the tank assembly, degradation of the storage pressure which might cause collapse of the tank assembly and the ability to store the tank assemblies without invalidating their previous acceptance. Adequate surveillance of the tanks in storage will be required to ensure there has been no excessive change in internal tank storage pressure, no excessive change in internal tank humidity, replacement of time/life hardware if required, no break in ambient conditions and no relaxation of safety precautions.

Section 16

BASELINE COST ESTIMATE

16.1 GROUNDRULES

The data presented are the results of a bottom-up cost estimate for the three candidate droptank designs (A, B, C) to design, develop, and produce 900 droptanks by 1986. The DDT&E phase of the program extends from 1972 through 1976. The DDT&E costing includes the costs of producing 6 test tanks using soft tooling. The production phase of the program extends from 1977 to 1986, with a peak production rate of 65 sets per year being reached in 1975.

While the DDT&E portion is composed entirely of nonrecurring costs, the production phase includes both nonrecurring and recurring costs. The nonrecurring production cost is largely composed of manufacturing planning and tooling as well as the purchase of special production machinery.

In order to be able to compare results, it was decided to use the same uninflated 1970 labor rates as used by Lockheed for the stage-and-one-half droptank estimate established at the end of 1970 (see Table 16-1).

16.2 RESULTS

Tables 16-2 through 16-6 summarize the costing results for the 3 candidate tank configurations. Table 16-2 shows the total program costs and its nonrecurring and recurring costs distribution with the latter comprising about 85% of total program cost. Configuration B shows a clear cost advantage of $60 million over Configuration A and a $78 million advantage over Configuration C. The DDT&E costs of Configuration B are $4 million higher than those of Configuration A which can be considered to represent an investment toward a $64 million cost saving in total production cost. Configuration C shows the highest costs in all three categories, i.e., the highest overall cost.

Table 16-3 presents the distribution of the DDT&E costs. The results here are very similar, with only a $3.9 million or 7 percent difference between highest and the lowest. The cost difference between Configuration A and B is accounted for by the number of test and manufacturing process development activities associated with the weld-bond process. Table 16-4 shows the nonrecurring production costs distribution. The difference here are larger than in DDT&E with a $9 million or 15 percent spread between the highest and lowest value.

Table 16-5 presents the recurring production costs. Configuration B shows a cost advantage of $67 million over A and $72 million over C. Sixty-three million of the $67 million difference from A to B is in the manufacturing and product assurance categories. The manufacturing costs of Configuration C are $32 million higher than those for Configuration B; in addition the raw material cost for Configuration C is $42 million higher than for Configuration B, which causes total production cost of Configuration C to be the highest.

The recurring manufacturing costs comprise 50 to 55 percent of the total program costs. A breakdown of the major cost elements is shown in Table 16-6. The key manufacturing cost elements are the tank fabrication and assembly. Configuration B, weld-bonded tank, is $51 million less in costs as compared to Configuration A and $30 million less compared to Configuration C. This significant cost advantage is due to the economics of weld-bond construction.

Table 16-1

Functional Labor Rates

	DDT&E $/Hr	Production $/Hr
Manufacturing	16.90	15.10
Engineering & Program Mgmt.	18.20	16.95
Product Assurance	15.95	14.40

Table 16-2

Total Program Costs

	Design Configuration		
	A ($ Millions)	B ($ Millions)	C ($ Millions)
Nonrecurring			
DDT&E	54	58	58
Production	60	63	69
Recurring			
Production	650	583	655
	764	704	782

Table 16-3

DDT&E Costs

	Design Configuration A ($ Millions)	B ($ Millions)	C ($ Millions)
Program Management	2.8	2.8	2.8
Engineering	21.7	21.7	21.7
Test and Operations Support	8.3	10.3	8.3
Manufacturing	16.8	18.1	19.7
Product Assurance	1.8	1.9	2.3
Material	2.6	2.7	3.1
Total	54.0	57.5	57.9

Table 16-4

Nonrecurring Production Costs

	Design Configuration A ($ Millions)	B ($ Millions)	C ($ Millions)
Manufacturing	46	47	50
Product Assurance	2	2	2
Raw Materials	3	4	4
Special Machinery	9	10	13
Total	60	63	69

Table 16-5

Recurring Production Costs

	Design Configuration A ($ Millions)	B ($ Millions)	C ($ Millions)
Manufacturing	423	367	399
Product Assurance	57	50	54
Program Management	8	8	8
Support Engineering	3	3	3
Raw Materials	67	62	104
Purchased Components	92	93	87
Total	650	583	655

Table 16-6

Recurring Manufacturing Costs

	Design Configuration A ($ Millions)	B ($ Millions)	C ($ Millions)
Structures Fabrication & Assembly	219	168	198
Subsystem Fabrication	75	75	75
Subsystem Installation	10	10	10
Insulation Application	56	56	56
Cleaning	10	10	10
Test and Checkout	4	4	4
Chemical Processing	4	1	3
Rework and Changes	27	23	25
Manufacturing Services	18	20	18
Total	423	367	399

Section 16A

TRADEOFF STUDY RESULTS

16A.1 DROPTANK DESIGN COMPARISON

Figure 16A-1 presents the results of the initial study phase and provides an overview comparison of the major droptank designs evaluated (Concept A — aluminum, fusion-welded; Concept B — aluminum, weld-bonded; Concept C — stainless steel, fusion-welded). Concept B shows the lowest relative cost for the three candidate concepts. The saving of approximately $62 million over a fusion-welded aluminum tank design and $77 million over a fusion-welded stainless steel tank design is basically attributed to the lower production costs associated with the weld-bond design (see Section 14 for Production Cost Breakdown). Concept B, the aluminum weld-bonded tank, was therefore used as the baseline for the Application Study phase of this task.

16A.1.1 Droptank Material Comparison

The result of the droptank material tradeoff study between 2219-T81 aluminum and 301 stainless steel is presented in Fig. 16A-2. Use of aluminum as the tank material shows a saving of approximately $15 million over stainless steel. This is accounted for chiefly because of the lower fabrication cost of the aluminum tank. The lighter weight of the stainless steel tank, caused by the better strength-to-density ratio of the material for pressure vessel applications, is offset by the more difficult and expensive welding procedures required. The stainless steel tank requires both spot-welding (for strength) and seam-welding (for leak-proofing) of minimum gage material (which is hard to handle). (See Sections 8 and 14 for manufacturing details.) The higher DDT&E costs for stainless steel are caused by higher test article manufacturing and material costs.

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DROPTANK DESIGN COMPARISON

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	TANK DESIGN: CONFIG. A – ALUMINUM FUSION-WELDED	CONFIG. B – ALUMINUM WELD-BONDED	CONFIG. C – STAINLESS STEEL FUSION-WELDED
• BASIC TANK WEIGHT	(5,110 LB) $ 2.6	(4,880 LB) $ 0.8	(4,784 LB) REF WT
DDT&E COSTS	$ 54	$ 58	$ 58
PRODUCTION COSTS	$710	$646	$724
COMPARISON TOTAL	$766.6	$704.8	$782
RELATIVE COST	$-15.4	$-77.2	REF.

• DROPTANK WEIGHT SENSITIVITY = $8,000/LB

Fig. 16A-1

D03830

Fig. 16A-1

LOCKHEED

DROPTANK MATERIAL TRADEOFF STUDY

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	TANK MATERIAL FUSION-WELDED: 2219-T81 ALUMINUM	TANK MATERIAL FUSION-WELDED: 301 STAINLESS STEEL
*BASIC TANK WEIGHT	(5,110 LB) $ 2.6	(4,784 LB) REF WT
DDT&E COST	$ 54	$ 58
PRODUCTION COST	$710	$724
COMPARISON TOTAL	$766.6	$782
RELATIVE COST	$-15.4	REF

* DROPTANK WEIGHT SENSITIVITY = $8,000/LB

Fig. 16A-2

D03831

Fig. 16A-2

16A.1.2 Droptank Joining Method Comparison

The tank manufacturing joining methods investigated were fusion-welding and weld-bonding. Weld-bonding is a relative new process which uses a glue bond joint with intermittent spotwelds through the glue to provide clamping pressure for the glue bond, positioning while the glue is uncured, and additional strength because of the traditional weld nugget formation. This process has been successfully used for structural fabrication of aircraft fuselages and space vehicle shrouds and has had some development testing for tank application at cryogenic temperatures. Fusion-welding is the classical cryogenic-tank fabrication-joining method.

A comparison study of two different aluminum tank designs – one using fusion seam-welding and one using weld-bonding – was made to evaluate the effect of these joining methods upon total program cost. Figure 16A-3 shows the results of this study. These results indicate a total cost saving of approximately $62 million by using the weld-bond method. This saving is attributed to both the lighter weight tank which results from use of closer tolerance material and the lower production costs associated with using unchem-milled sheet stock and loose fit-up tolerances between the panels glued to the doubler frame. (See Section 14 for manufacturing details.) The conservative $5 million process development cost shown for qualifying the weld-bond technique is significantly offset by the lighter weight, lower production costs resulting from application of this technique.

16A.2 DROPTANK TRADEOFF STUDY RESULTS

A total of ten (10) separate design tradeoff studies were performed on the major tank subsystems, methodologies, and critical manufacturing parameters. The results of these studies, which are presented throughout the sections of Parts I and II of this report, are summarized in Fig. 16A-4 and provide a baseline design concept for use in the Application Study part of this report (Part III). These tradeoff study results, when used with the inputs received

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FABRICATION JOINING METHOD TRADEOFF STUDY

(COST IN $MILLIONS)

MAJOR COST PARAMETERS	FABRICATION JOINING METHOD FOR 2219-T81 ALUMINUM TANKS	
	WELD-BOND	FUSION-WELD
* BASIC TANK WEIGHT	(4,880 LB) REF WT	(5,110 LB) $ 1.8
PRODUCTION COSTS	$646	$710
PROCESS DEVELOPMENT COSTS	$ 5	$ 1
COMPARISON TOTAL	$651	$712.8
RELATIVE COST	REF	$ + 61.8

* DROPTANK WEIGHT SENSITIVITY = $8,000/LB

Fig. 16A-3

D03832

Fig. 16A-3

from the other shuttle study contractors, Grumman Aircraft Company (GAC), North American Rockwell (NAR) and the McDonnell Douglas Company (MDAC) (see Fig. 16A-5), constituted the basic design requirements used to perform the Application Study to arrive at an optimum droptank design for both the GAC and NAR orbiters. (Only droptank costs were evaluated for MDAC; these were based upon their own tank design weight.)

LOCKHEED

DROPTANK TRADEOFF STUDY RESULTS

TRADEOFF STUDY	DESIGN DECISION
• ATTACH/SEPARATION SUBSYSTEM	LIGHTEST WEIGHT, EXPENDABLE
• RETROROCKET SUBSYSTEM	DEVELOP NEW, LIGHTER MOTORS
• ACCEPTANCE TESTING	USE LIGHTWEIGHT TANK, AMBIENT TEMP, HYDROPNEUMATIC TEST METHOD
• TPS SUBSYSTEM	USE CONCEPT WITH TANK-CORK-FOAM BUILDUP
• LH_2 FEED SYSTEM DISCONNECT	USE SPOOL WITH PYRO CUTTER
• PRESSURE/VENT LINE ROUTING	ROUTE LINES INSIDE ORBITER
• TANK HANDLING CONCEPT	USE LIGHTWEIGHT PRESSURE STABILIZED TANK
• TANK MATERIAL	ALUMINUM
• TANK JOINING METHOD	WELDBOND
• TANK DESIGN CONFIGURATIONS	CONFIGURATION "B"

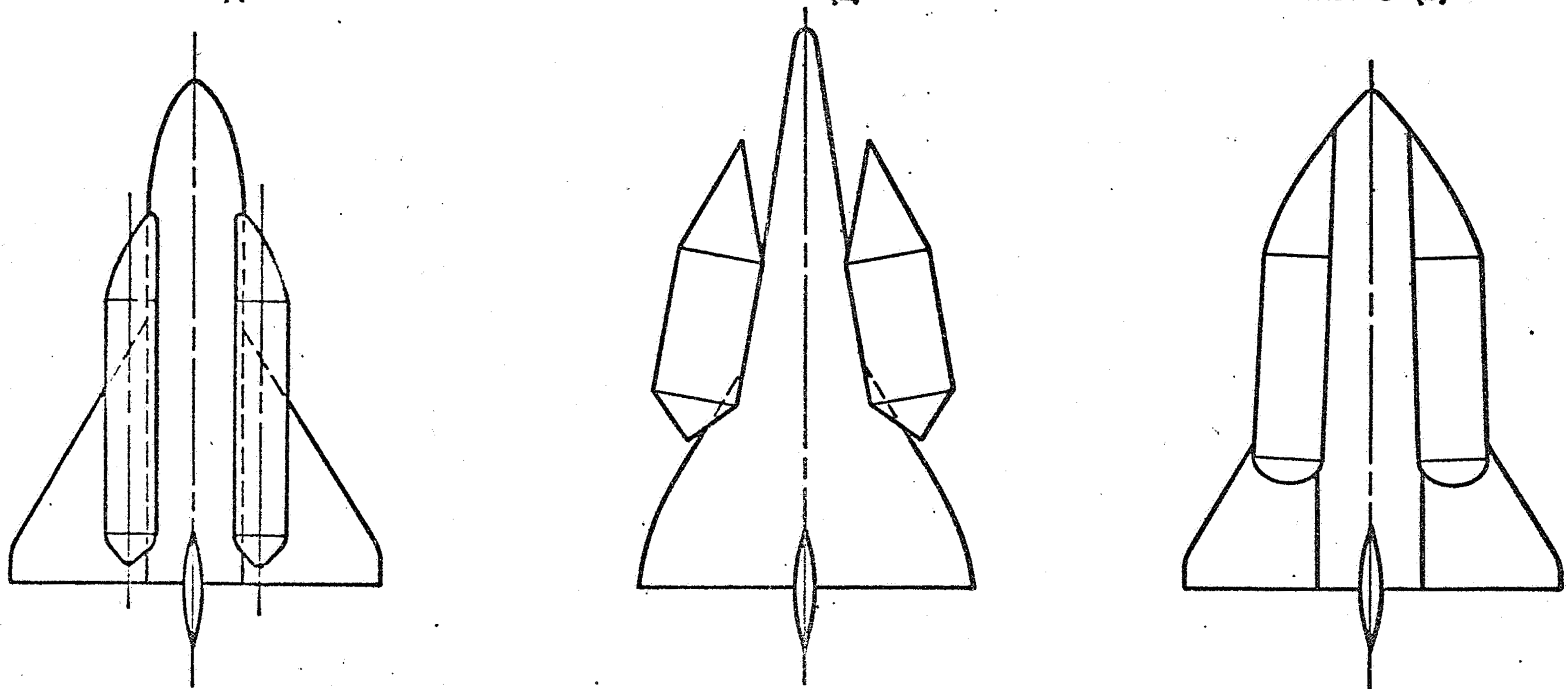
Fig. 16A-4

D03899

Fig. 16A-4

LOCKHEED

INPUTS FOR APPLICATION STUDY



	GAC (1)	NAR (2) CONCEPT 0021	MDAC (3)
TANK DIA	14.9 FT	17.2 FT	21.5 FT
TANK LENGTH	102 FT	71.5 FT	105.3 FT
TANK VOLUME	13,666 FT^3	12,804 FT^3	28,500 FT^3
TANK STRUCTURE WEIGHT	4,981 LB	9,920 LB	13,606 LB

SOURCE: (1) OVERVIEW AND STUDY STATUS, "EXTERNAL HYDROGEN TANK ORBITER, HEAT SINK BOOSTER," 28 APRIL 1971
DRAWING 552L0190-511
(2) MIDTERM REVIEW, "ORBITER EXTERNAL HYDROGEN TANK STUDY," 12 MAY 1971
(3) THIRD STATUS REPORT, "EXTERNAL TANK STUDY," 25 MAY 1971

D03912(1)

Fig. 16A-5

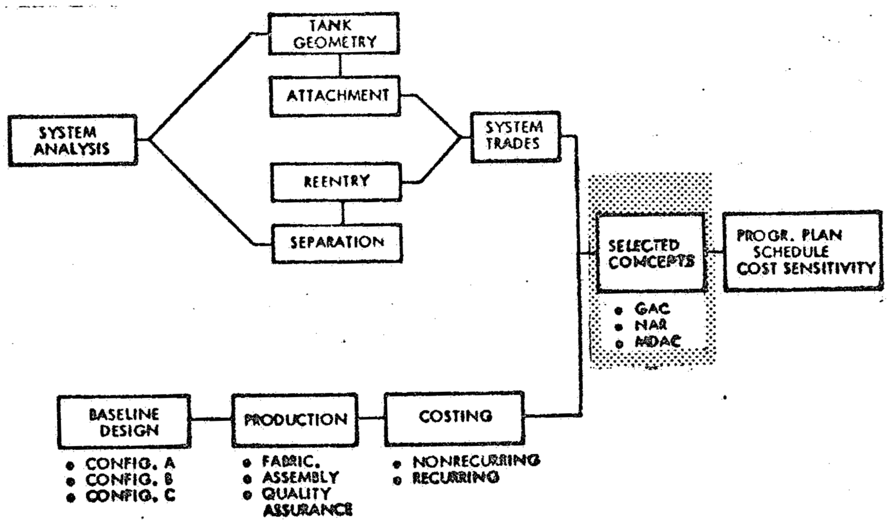
Fig. 16A-5

PART III

Part III
APPLICATION STUDY

Part III describes the study activities as highlighted in the figure below. It describes the application of the results of Parts I and II to three external tank orbiter configurations (GAC, NAR and MDAC) as they existed at the beginning of the application study (1 June 1971).

For the GAC and NAR configurations, it describes the resulting tank design and gives associated manufacturing and program cost estimates; and for the MDAC configuration a CER program cost estimate. A summary of results completes the report on the Application Study.



The following Application Study design assumptions were derived from the results of the Part I and Part II studies (see Section 16A).

- Weld-Bonded Design (Configuration B)
- Aluminum 2219
- Tank L/D – 8
- Straight Cone
- Intact Impact
- Pressure-Stabilized Tank
- Expendable Tank Attach Structure
- Reusable Vent Pressure Line
- Pyrotechnic Type Feedline Separation
- New Retrorocket – Aft Installation
- Hydropneumatic Proof Pressure Test

The above assumptions, along with the detailed design analyses and layout drawings, produced for the baseline Concept B and the data received from the orbiter vehicle design contractors (see Fig. 16A-5), provided the starting point for tank designs for each of the applicable orbiter vehicles (GAC and NAR).

Section 17
GAC CONCEPT

Groundrules and assumptions reflecting lessons learned during Part I and Part II of this study were used to define conceptual droptank arrangements and tank designs based on the available GAC concept definition. General arrangements, insulation concepts, and tank structural assembly and associated weights were defined; a manufacturing cost analysis performed; and program costs estimated in the same manner as that used for the well-established baseline Concept B.

17.1 ORBITER/TANK ARRANGEMENT

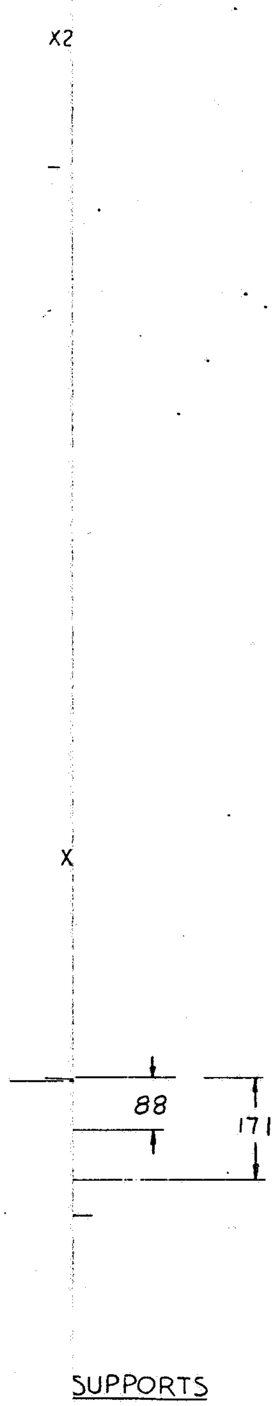
The general arrangement illustrating the external mounting of an LH_2 droptank system on a reusable orbiter vehicle (Grumman concept) is indicated in design drawing SKG 100721 (Fig. 17-1). The external tanks (one shown) provide for a required volume of approximately 13,700 cu ft. The overall length of each tank system is approximately 98 ft and was limited by the orbiter bow shock wave at its forward end and the orbiter wing trailing edge at its aft end. This results in a tank diameter (I.D.) of 15 ft which results in a tank L/D of 6.5. The structural attach interface stations on the orbiter were assumed on the basis that the aft attach orbiter station (Sta 1576 – Thrust Structure Bulkhead) was the best available aft hard point area and the forward attach orbiter station (Sta 690 – Frame) would be in the fuselage area where framing approximately every 20 in. was available for a forward hard point attachment.

The droptank system installation is shown in design drawing SKT 100723 (Fig. 17-2), and identifies the dimensions and locations of plumbing and plumbing equipment for the pressurization, venting, feed, and recirculation lines for the liquid hydrogen tank, as well as the operational instrumentation for temperature, pressure and liquid level-sensing.

The drawing also identifies the insulation required to protect the tanks for intact entry. For intact entry (baseline approach) 0.30-in. thick cork panels are bonded to the metallic (aluminum) droptank system surfaces and then polyurethane foam is sprayed over the cork and machined to provide a foam-insulation thickness of 0.75 in. Remaining subsystems identified are the retrorocket and electrical systems. A retrorocket system is installed on the aft end of each tank system and the bulk of the electrical system is installed within the nose fairing. A mechanical/optical separation sensor system employing the use of a tapelike device is required at two places (forward and aft) on each tank. The forward sensor system is installed in the vicinity of the forward attach strut system, and the aft sensor system is installed between the orbiter and tank in the vicinity of the retrorocket installation.

Droptank assembly details are shown in design drawing SKG 100719 (Fig. 17-3). The 15-ft diameter liquid hydrogen tank is constructed from 2219-T87 aluminum, using standard sheet stock for the tank skin panels. The tank assembly generally consists of a cylinder, forward cone, a forward tank end, and an aft tank end. An aluminum tank skirt is also provided at the forward end of the tank cone. To this skirt is attached a short fairing, constructed from magnesium/wood, which protects the propellant system line-valving associated with the pressurization and venting system, a cluster of tank-dome-mounted temperature sensors, and the bulk of the electrical system equipment.

The method of construction consists primarily of weld-bonding roll-formed skin panels to a frame system (doublers) fusion-welded together to form a cagelike arrangement in the shape of the desired tank geometry. The details of the tank elements are similar in concept to those described for baseline Configuration B, Section 9, and as shown in design drawing SKS 100718 (Fig. 18-2).



PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL DESCRIPTION OR NOTE	MATERIAL SPECIFICATION	ZONE	ITEM NO

PARTS LIST

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

GENERAL ARRANGEMENT

SIZE E

ement, External LH_2 Tank

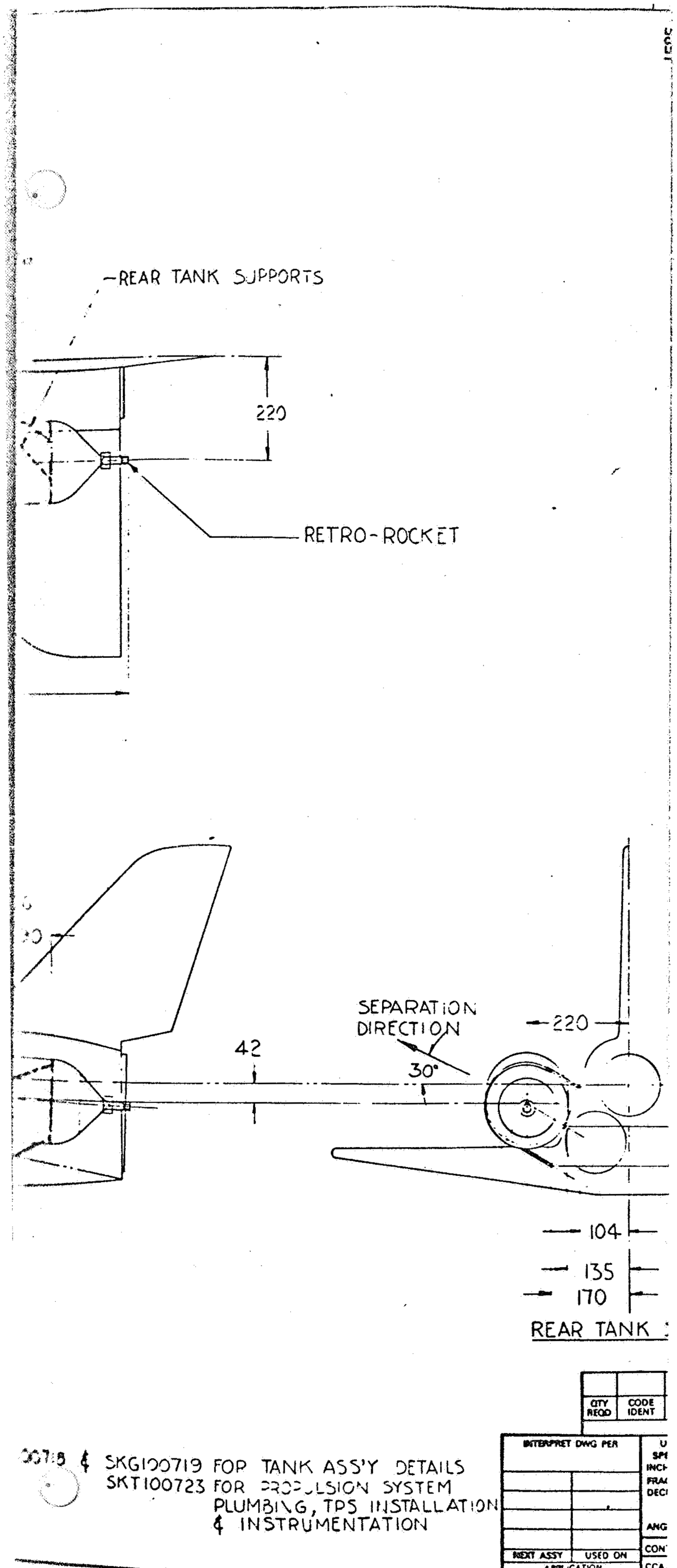
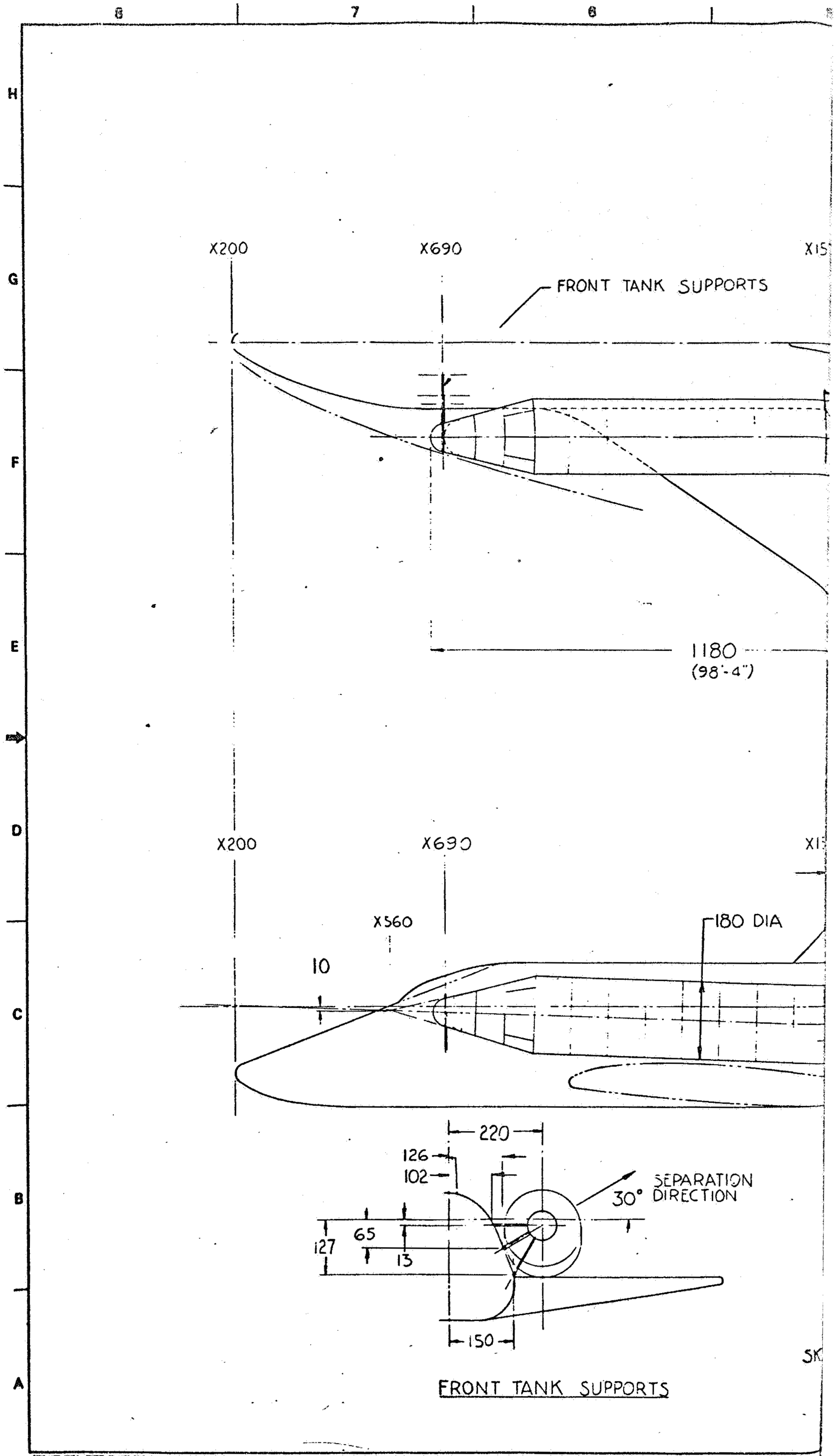


Fig. 17-1. General Arrang


8
7
6
H
G
F
E
D
C
B
A
X200
X690
FRONT TANK SUPPORTS
1180
(98'-4")
X200
X690
X560
10
180 DIA
220
126
102
SEPARATION DIRECTION
30°
65
127
13
150
FRONT TANK SUPPORTS

D SENSOR

QTY REQ'D	CODE	ITEM	SOURCE	ITEM NO.
		INSTRUMENT LIST		
22	●	POINT SENSORS (OPTICAL-TYPE)		40
8	□	TEMP TRANSDUCER	CEC	41
4	○	PRESSURE TRANSDUCER	CEC	42
4		PRESSURE SWITCH	PARKER	43
2		TAPE CONTAINER		44
2		PHOTO TRANSISTOR		45
1		TIMER AND TRANSISTOR LOGIC		46
1		POWER TRANSFER CONTROL		47
2		BATTERIES		48

ALL (REF)

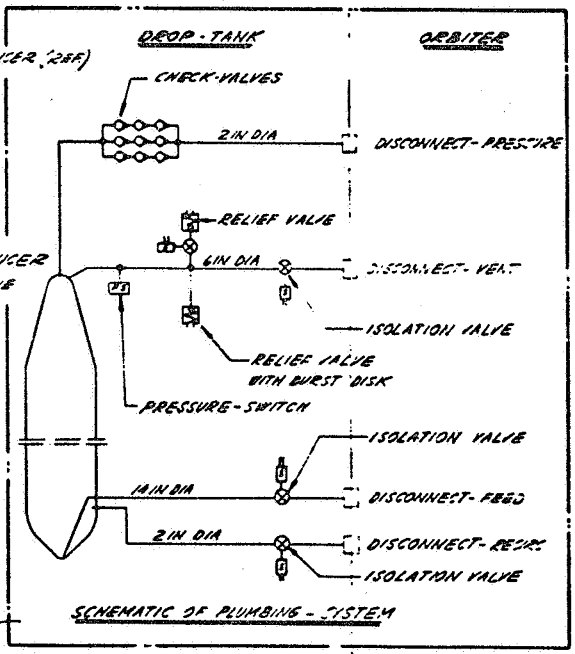
RE TRANSDUCER

LE COVER (REF)

TRANSDUCER (REF)

TRANSDUCER
FEED LINE

(REF)



WL 800

QTY	SOURCE	DESCRIPTION	MATERIAL	ITEM
1		BELLOW 6 IN DIA		35
2		BELLOW 2 IN DIA		34
1		BELLOW 14 IN DIA		33
AS REQ'D		FILLER		32
1		FITTING		31
1		FITTING		30
1		NULLIFIER		29
AS REQ'D		LEFKOWELD 109/SCRIM ADHESIVE		28
		CHEMSEAL 3547 COATING		27
		PAINT Y455 DYNATHERM		26
		BOND EPON 934/SCRIM CLOTH		25
		POLYURETHANE FOAM		24
AS REQ'D		ABLATIVE L=.30 IN	CORK	23
1		VORTEX SUPPRESSOR		22
1		VORTEX BAFFEL		21
1	6	DISCONNECT COUPLING, PRESSURE		20
1	5	GIMBAL JOINT, PRESSURE		19
9		CHECK VALVES 4 IN, PRESSURE		18
1	4	2.0 I.D. × .035 WALL PRESSURE LINE		17
1	6	DISCONNECT COUPLING, VENT		16
1		ISOLATION VALVE, VENT		15
1		RELIEF VALVE (BURST DISK), VENT		14
1		RELIEF VALVE, VENT		13
1	5	GIMBAL JOINT, VENT	AL WITH INCONEL BELLOWS	12
1	4	6.0 I.D. × .032 WALL, VENT LINE	2219 AL	11
1	6	DISCONNECT COUPLING, RECIRCULATION		10
1		ISOLATION VALVE, RECIRCULATION		9
1	5	GIMBAL JOINT, RECIRCULATION	AL WITH INCONEL BELLOWS	8
1	4	2.0 I.D. × .020 WALL, RECIRCULATION	2219 AL	7
1		STAND PIPE 14.0 I.D. × .049 WALL	FLUID LINE	6
1	6	DISCONNECT, COUPLING, FLUID LINE		5
1		ISOLATION VALVE, FLUID LINE		4
1	5	GIMBAL JOINT, FLUID LINE	AL WITH INCONEL BELLOWS	3
1	4	14.0 I.D. × .049 WALL FLUID LINE	2219 AL	2
1		SKG 100718 DROP TANK ASSY		1

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL DESCRIPTION OR NOTE	MATERIAL SPECIFICATION	ZONE	ITEM NO.

PARTS LIST

6 DISCONNECT WITH ISOLATION VALVE SIMILAR TO ROYAL, HADLEY 11397 OR RMD CC186

5 GIMBAL JOINTS SIMILAR TO SOLAR 38026

4 SOLAR, ARROWHEAD AND AMETEK TYPICAL HPE'S FOR LINES AND FITTING

3 MATERIAL LISTS ARE MADE UP FOR ONE SINGLE TANK.

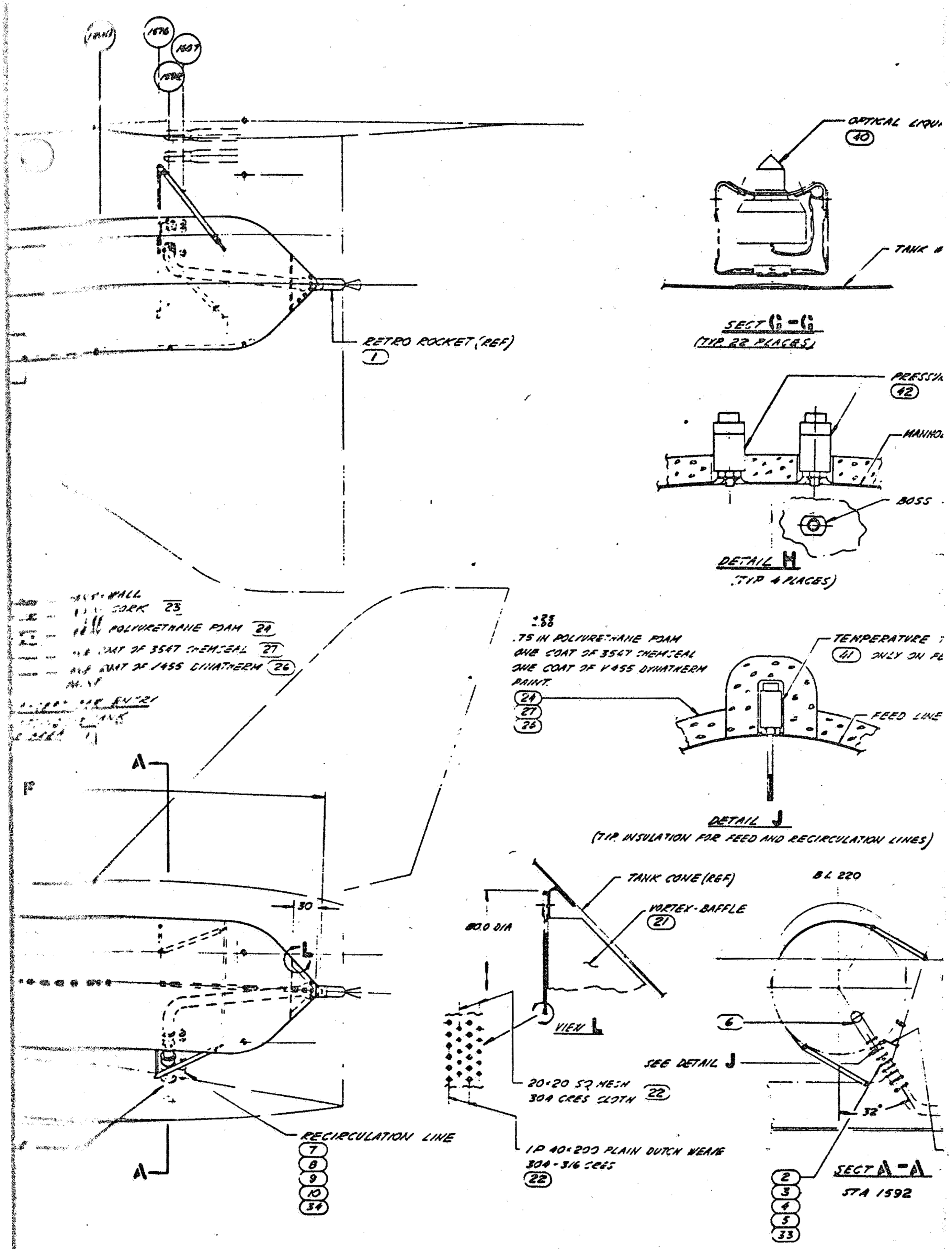
45
44

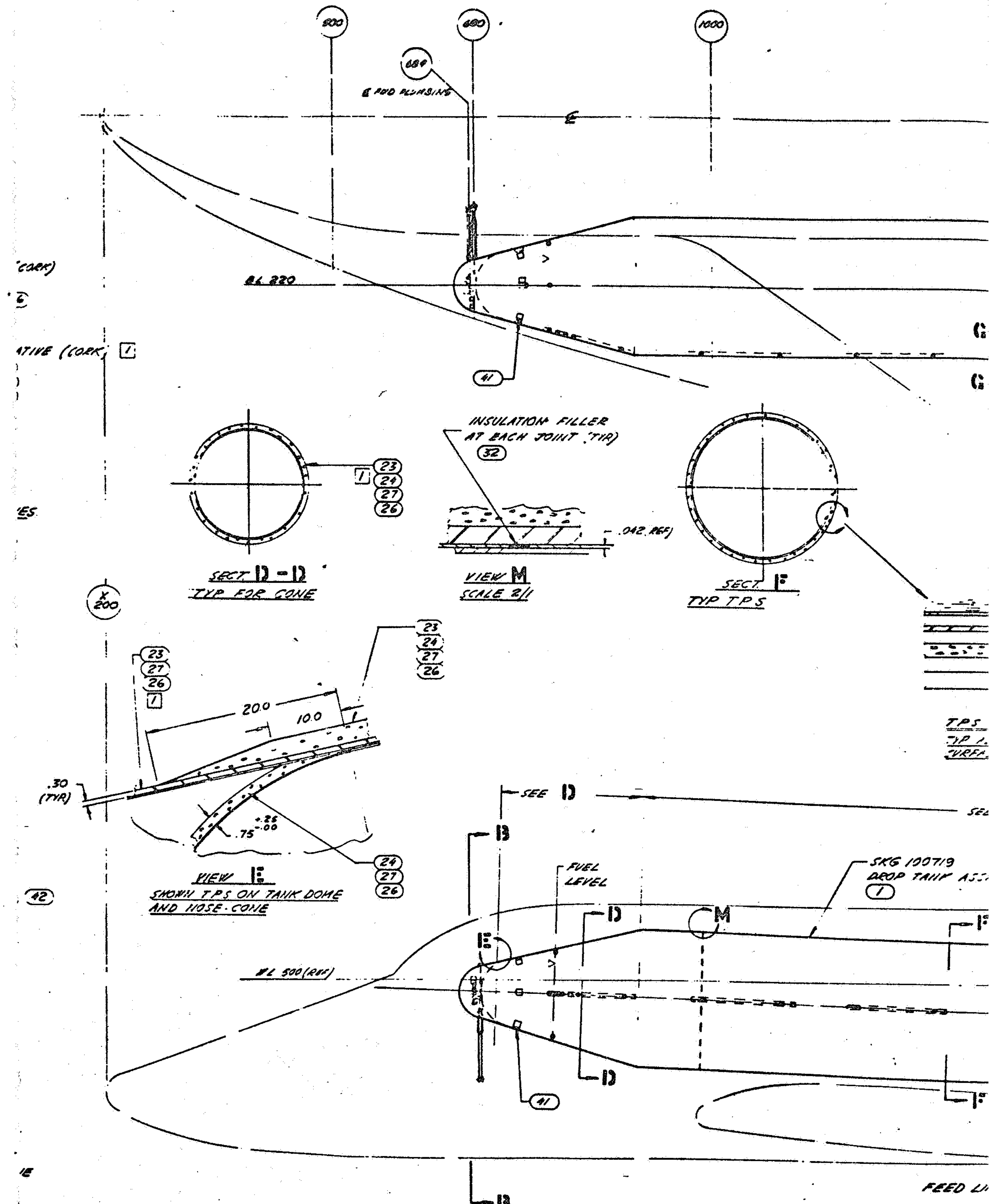
7 BOND THE CORK TO THE TANK-WALL AND USE LEFKOWELD 109/SCRIM ADHESIVE

NOTES:

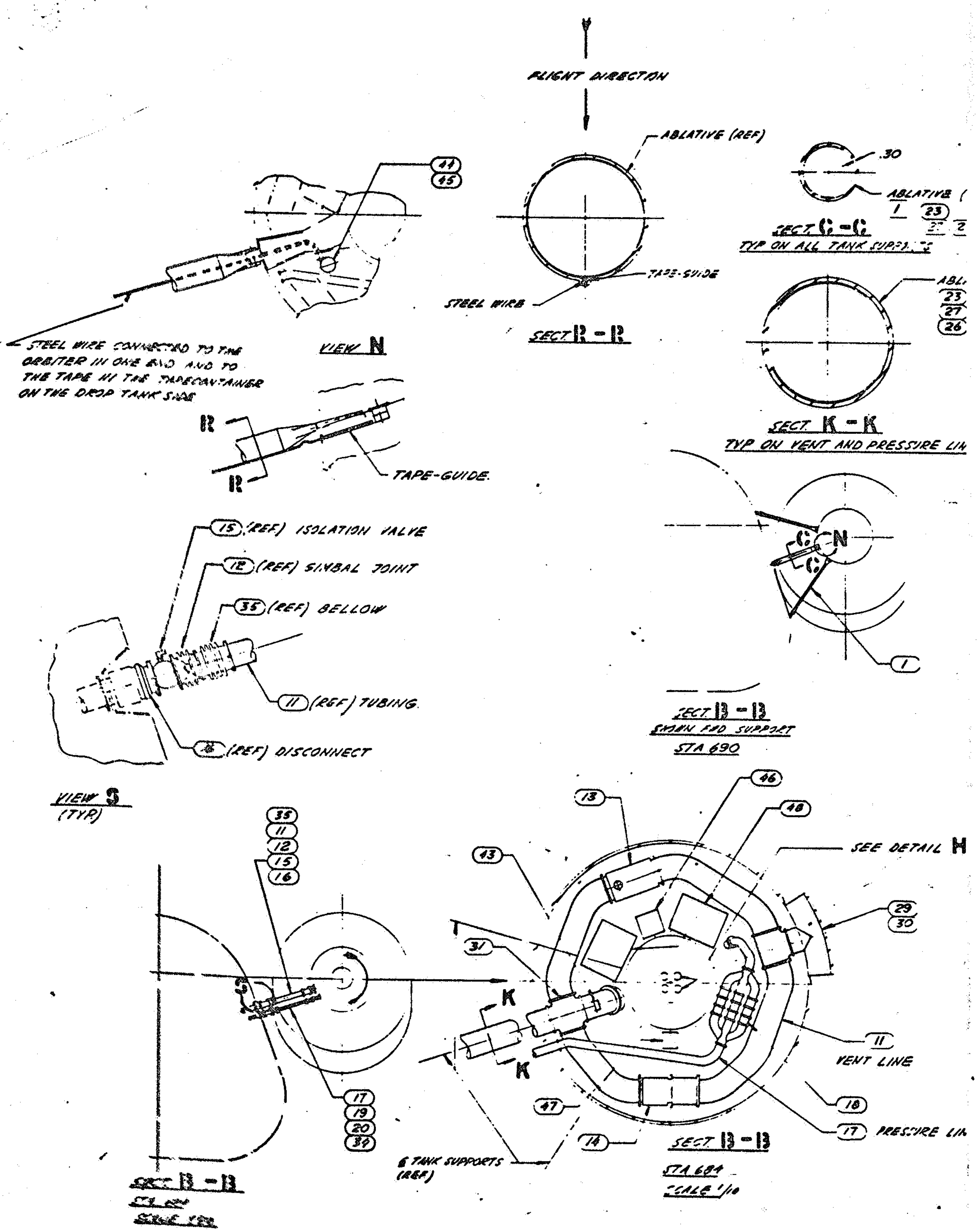
EFFECTIVITY DWG FOR		UNLESS OTHERWISE SPECIFIED DIMS ARE IN INCHES TOLERANCES ON: FRACTIONS = ± 1/16 DECIMALS: .X = ± .1 .XX = ± .03 .XXX = ± .010 ANGLES = ± 2 DEG	DATE / DR / APPD / APPD / ENGRG / CHK / APPD / APPD	LOCKHEED MISSILES & SPACE COMPANY A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION SUNNYVALE, CALIFORNIA
NEXT ASSY	USED ON	CONTR		DROP TANK INSTALLATION EXTERNAL [illegible]
APPLICATION		CCA/CEI		SIZE / CODE IDENT / DRAWING NO / REV / SCALE / SHEET

Fig. 17-2 Droptank Installation, External LH_2 Tank


RETRO ROCKET (REF)
1
OPTICAL LIQU
40
TANK
SECT G-G
(TYP 22 PLACES)
PRESSU
42
MANHO
BOSS
DETAIL H
(TYP 4 PLACES)
CORK 23
POLYURETHANE FOAM 24
COAT OF 3547 CHEMSEAL 27
COAT OF V455 DYNATHERM 26
.75 IN POLYURETHANE FOAM
ONE COAT OF 3547 CHEMSEAL
ONE COAT OF V455 DYNATHERM PAINT
24
27
26
TEMPERATURE
41 ONLY ON FE
FEED LINE
DETAIL J
(TYP INSULATION FOR FEED AND RECIRCULATION LINES)
A
A
30
L
RECIRCULATION LINE
7
8
9
10
34
TANK CONE (REF)
VORTEX-BAFFLE
21
80.0 DIA
VIEW L
20×20 SQ MESH
304 CRES CLOTH
22
1P 40×200 PLAIN DUTCH WEAVE
304-316 CRES
22
BL 220
6
SEE DETAIL J
32°
2
3
4
5
33
SECT A-A
STA 1592



800
880
1000
884
℄ AND PLUMBING
℄
BL 220
41
INSULATION FILLER
AT EACH JOINT (TYP)
32
23
24
27
26
.042 REF)
SECT D-D
TYP FOR CONE
VIEW M
SCALE 2/1
SECT F
TYP TPS
X 200
23
27
26
23
24
27
26
20.0
10.0
.30 (TYP)
.75
24
27
26
VIEW E
SHOWN TPS ON TANK DOME
AND NOSE-CONE
SEE D
B
FUEL
LEVEL
SKG 100719
DROP TANK ASS
D
M
E
WL 500(REF)
41
D
B
FEED LI
('CORK)
ATIVE (CORK,
ES
42



FLIGHT DIRECTION
ABLATIVE (REF)
TAPE-GUIDE
STEEL WIRE
SECT R - R
.30
ABLATIVE
SECT C - C
TYP ON ALL TANK SUPPORTS
SECT K - K
TYP ON VENT AND PRESSURE LIN
STEEL WIRE CONNECTED TO THE ORBITER IN ONE END AND TO THE TAPE IN THE TAPECONTAINER ON THE DROP TANK SIDE
VIEW N
TAPE-GUIDE.
15 (REF) ISOLATION VALVE
12 (REF) GIMBAL JOINT
35 (REF) BELLOW
11 (REF) TUBING
16 (REF) DISCONNECT
SECT B - B
SHOWN FWD SUPPORT
STA 690
VIEW S
(TYP)
SEE DETAIL H
VENT LINE
PRESSURE LIN
6 TANK SUPPORTS (REF)
SECT B - B
STA 684
SCALE 1/10
SECT B - B

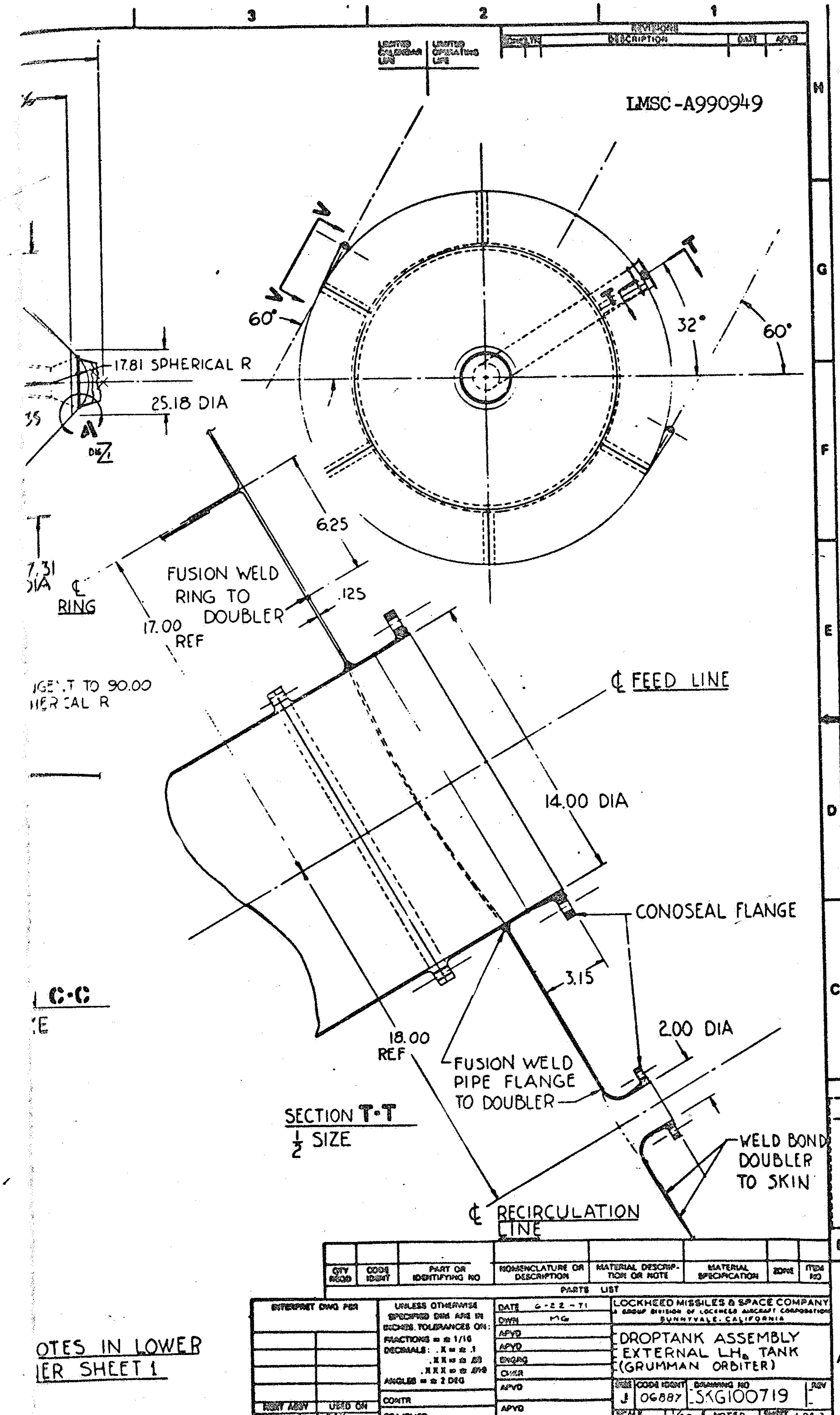
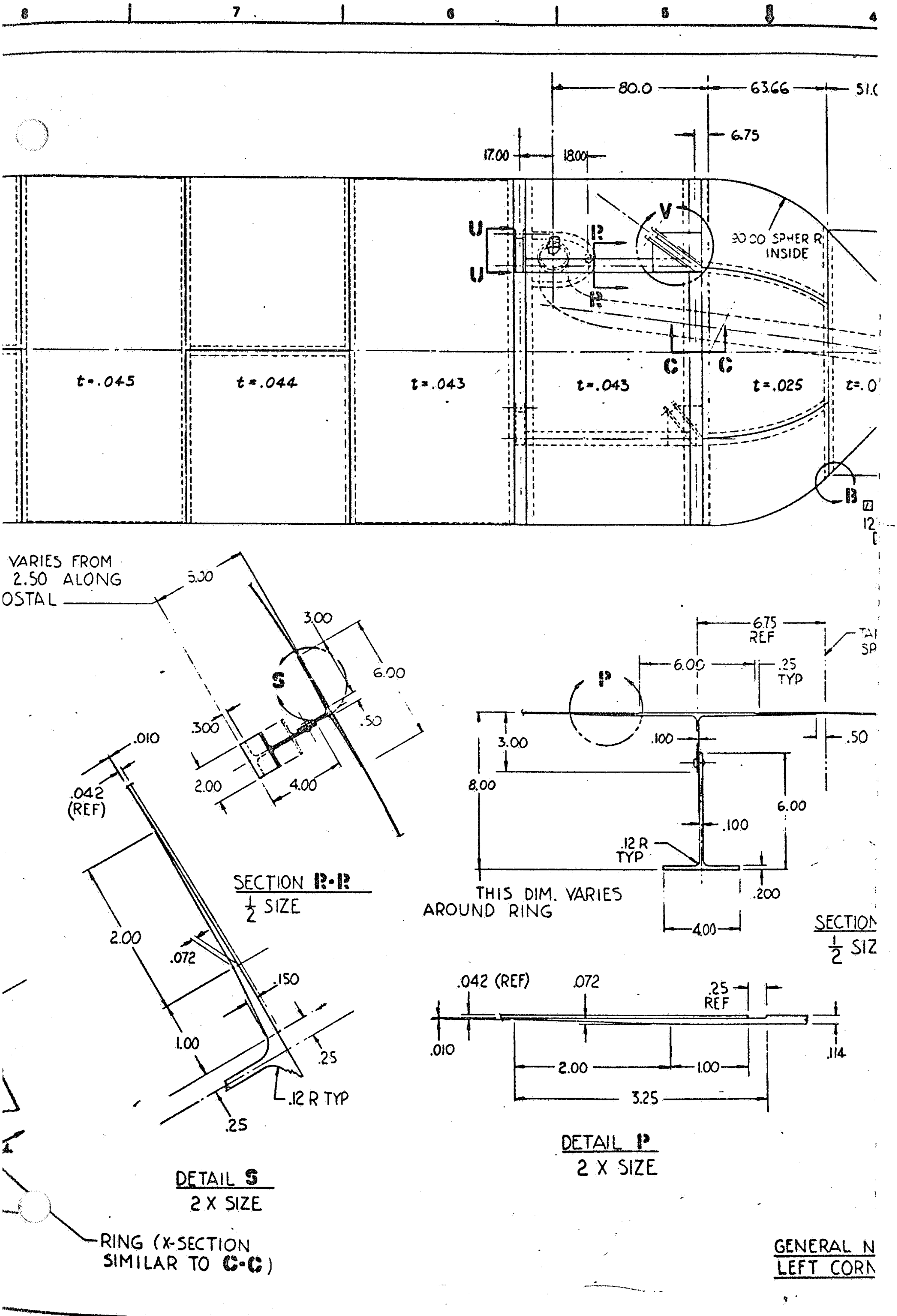
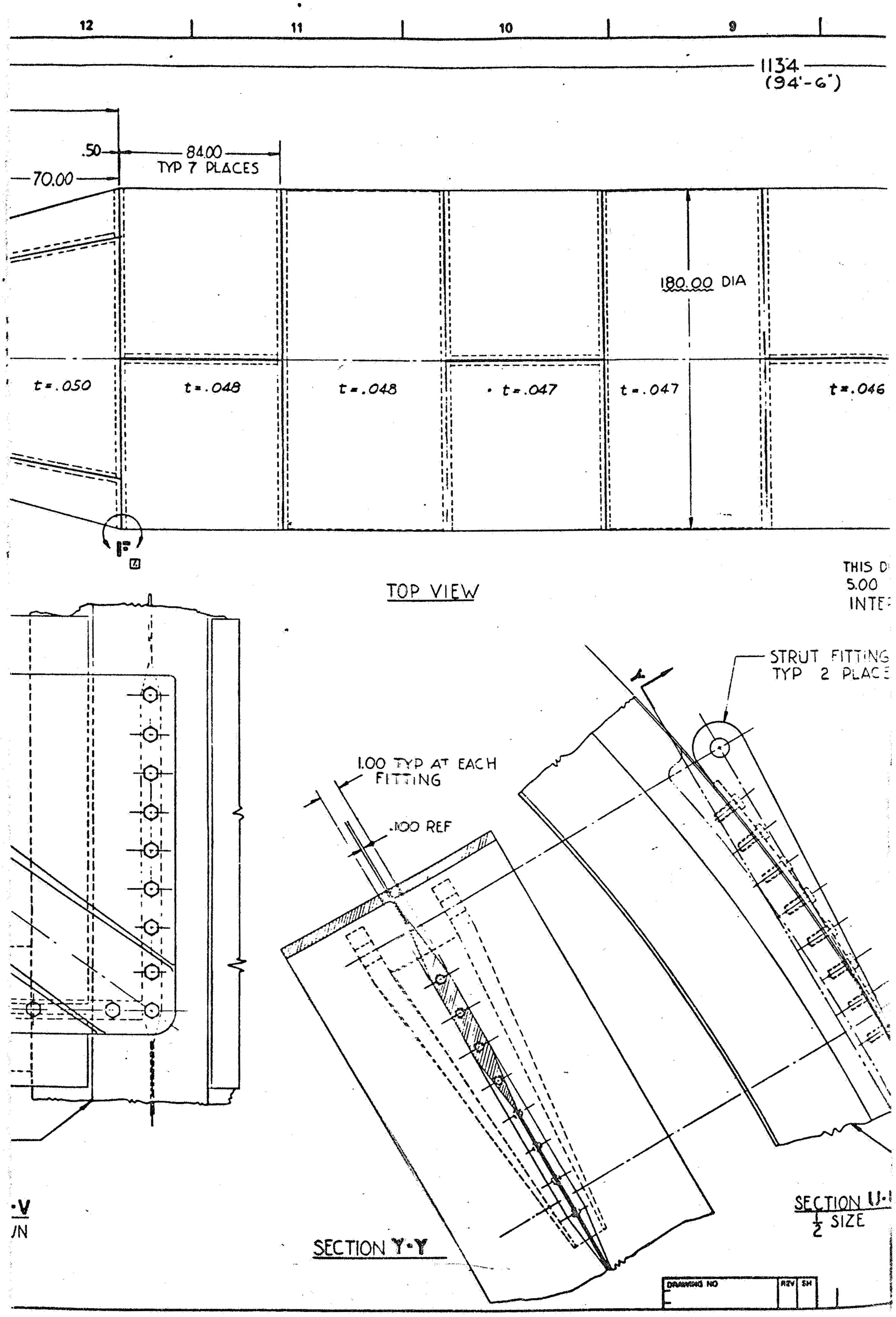


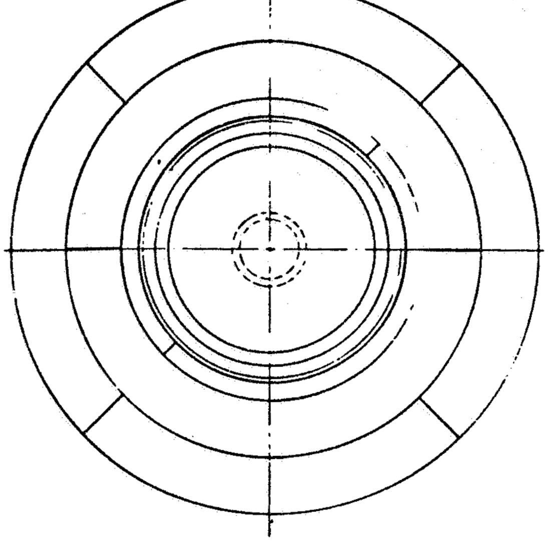
Fig. 17-3 Droptank Assembly, External LH$_2$ Tank (Sheet 2)

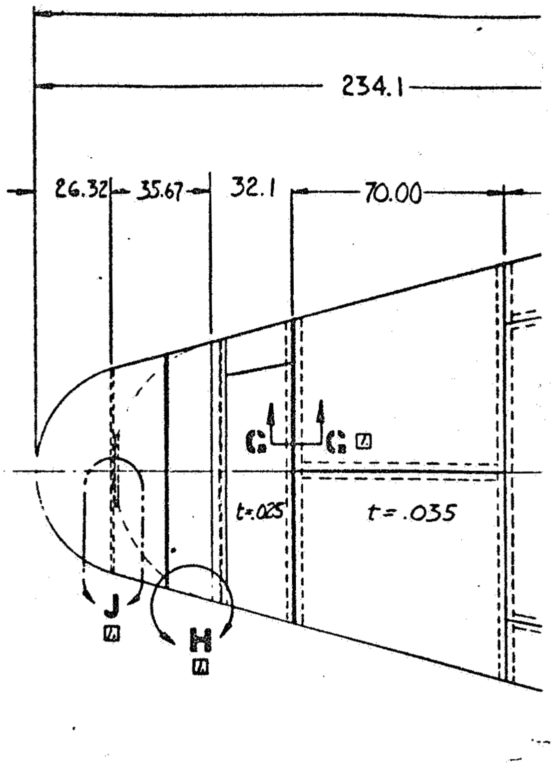


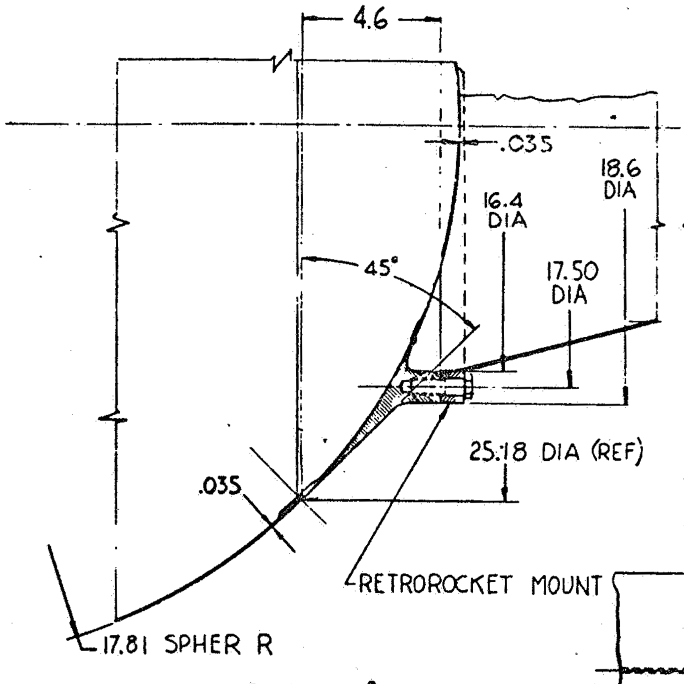
80.0
63.66
51.(
6.75
17.00
18.00
U
U
R
R
V
30.00 SPHER R
INSIDE
C
C
t=.045
t=.044
t=.043
t=.043
t=.025
B
VARIES FROM
2.50 ALONG
OSTAL
5.00
3.00
6.00
.50
.300
2.00
4.00
S
SECTION R-R
½ SIZE
.010
.042
(REF)
2.00
.072
.150
1.00
.25
.12 R TYP
.25
DETAIL S
2 X SIZE
6.75
REF
6.00
.25
TYP
P
3.00
.100
.50
8.00
6.00
.100
.12 R
TYP
THIS DIM. VARIES
AROUND RING
.200
4.00
SECTION
½ SIZ
.042 (REF)
.072
.25
REF
.010
.114
2.00
1.00
3.25
DETAIL P
2 X SIZE
RING (X-SECTION
SIMILAR TO C-C)
GENERAL N
LEFT CORN



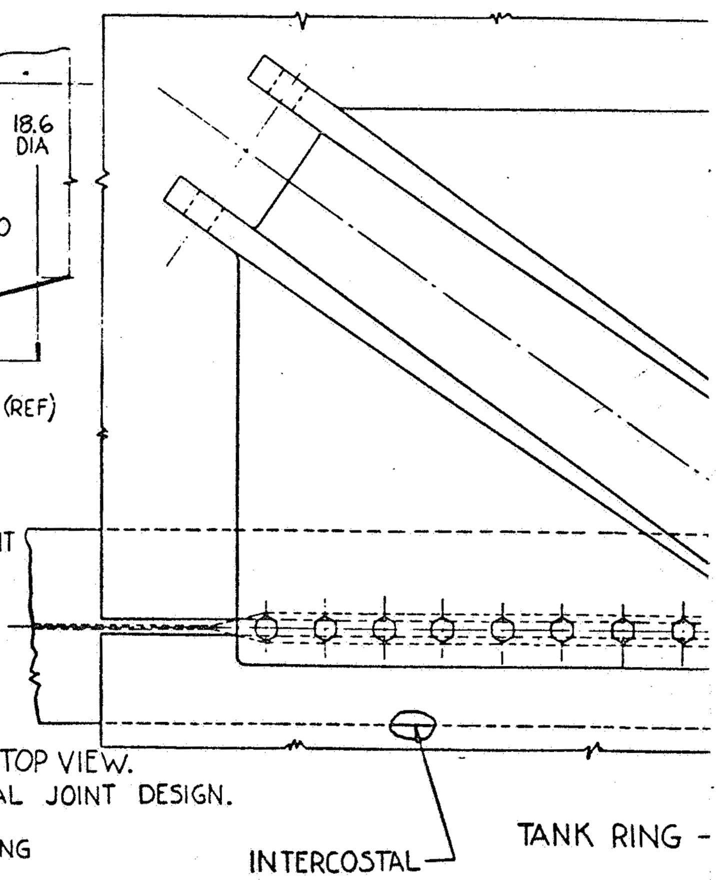
12
11
10
9
1134
(94'-6")
.50
84.00
TYP 7 PLACES
70.00
180.00 DIA
t=.050
t=.048
t=.048
t=.047
t=.047
t=.046
F
TOP VIEW
THIS D
5.00
INTE
STRUT FITTING
TYP 2 PLACE
1.00 TYP AT EACH
FITTING
.100 REF
SECTION Y-Y
SECTION U-
1/2 SIZE
-V
/N
DRAWING NO
REV
SH







DETAIL A
$\frac{1}{2}$ SIZE



DETAIL V, VIEW V
UPPER FITTING SHOW
LOWER FITTING OPP

8. TANK WALL THICKNESSES SHOWN IN TOP VIEW.
7. REFER TO SKS100718 DETAIL C FOR TYPICAL JOINT DESIGN.
6. REFER TO SKT100723 FOR TANK INSTRUMENTATION & CONTROLS, PLUMBING AND INSULATION INSTALLATIONS.
5. ALUMINUM ALLOY PARTS FORMED BY SPINNING ARE 2219-T81.
4. TANK VOLUME 13900 FT^3
3. REFER TO SKG100721 FOR TANK GENERAL ARRANGEMENT.
2. TANK MAT'L 2219-T87 AL ALLOY, EXCEPT AS NOTED.

▢ THIS DETAIL IS SHOWN ON DRWG SKS100718, EXCEPT AS MODIFIED HEREIN.

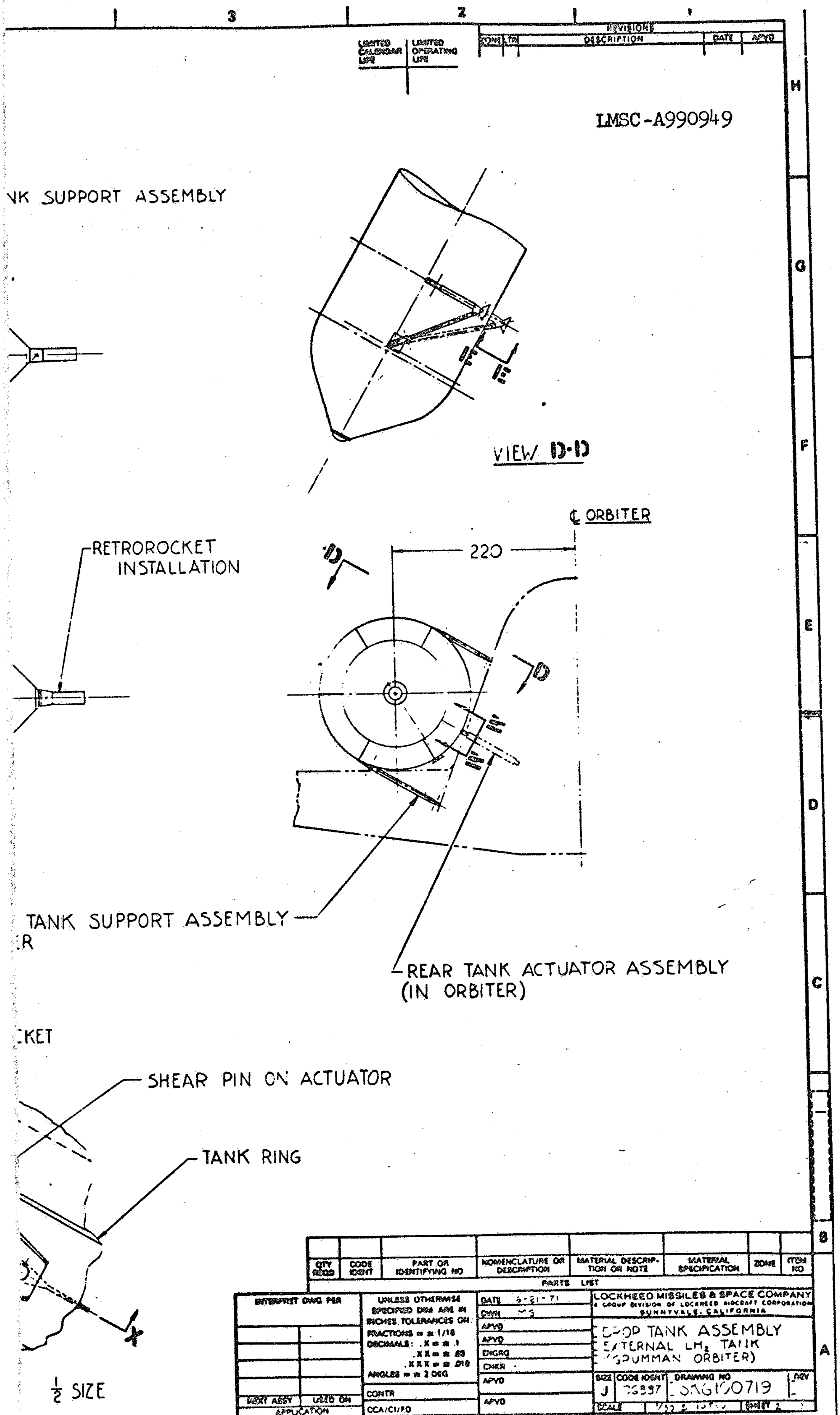
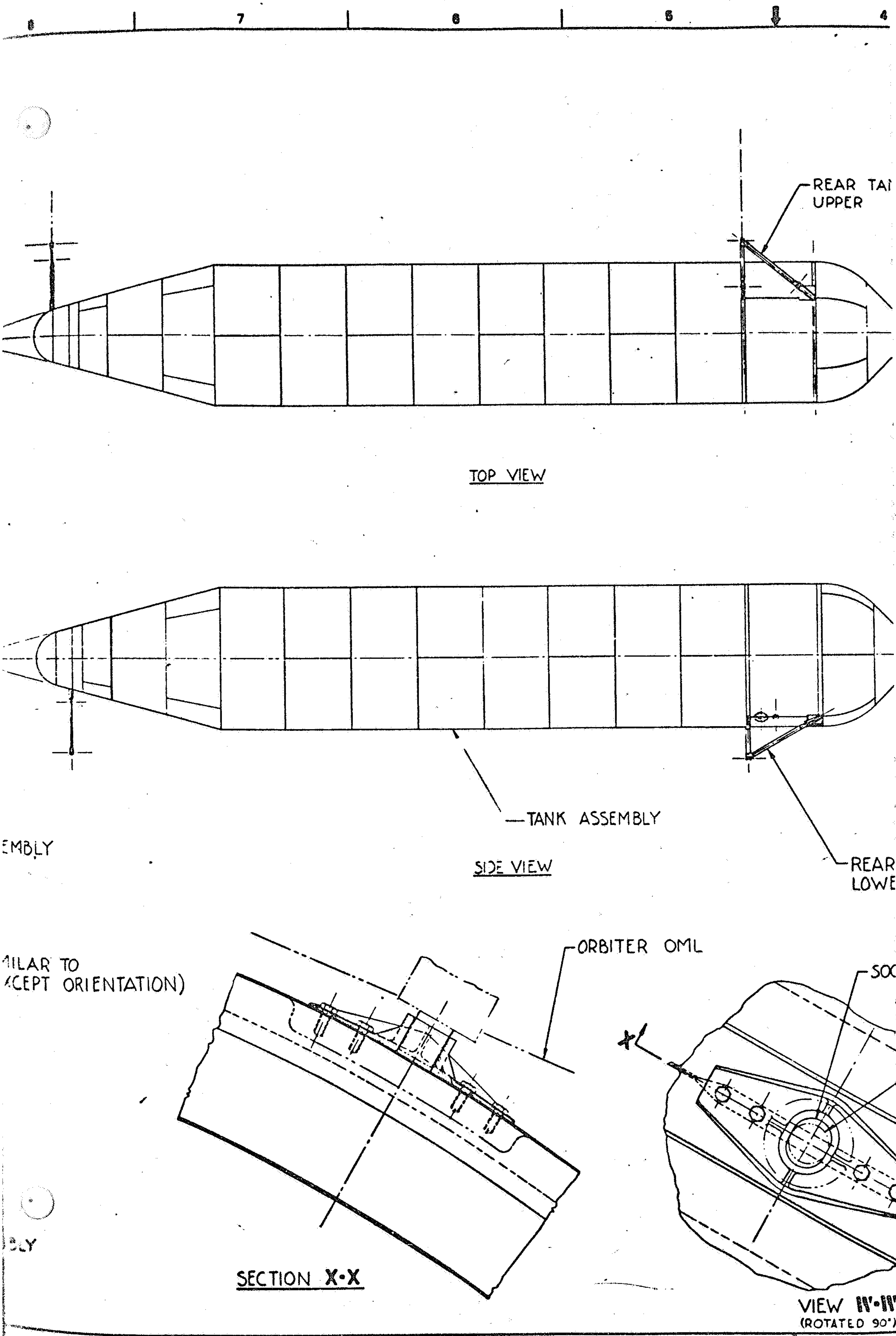
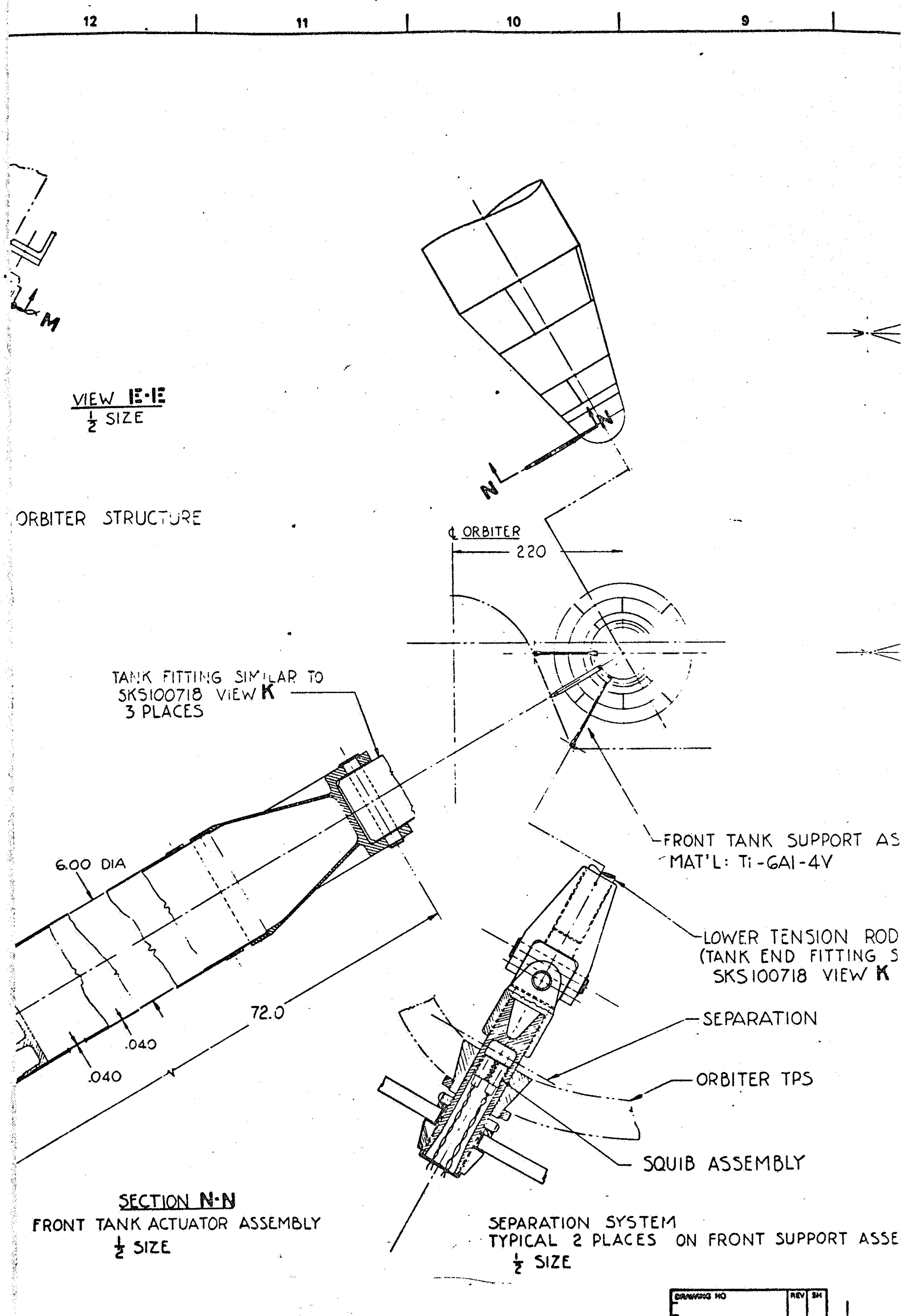


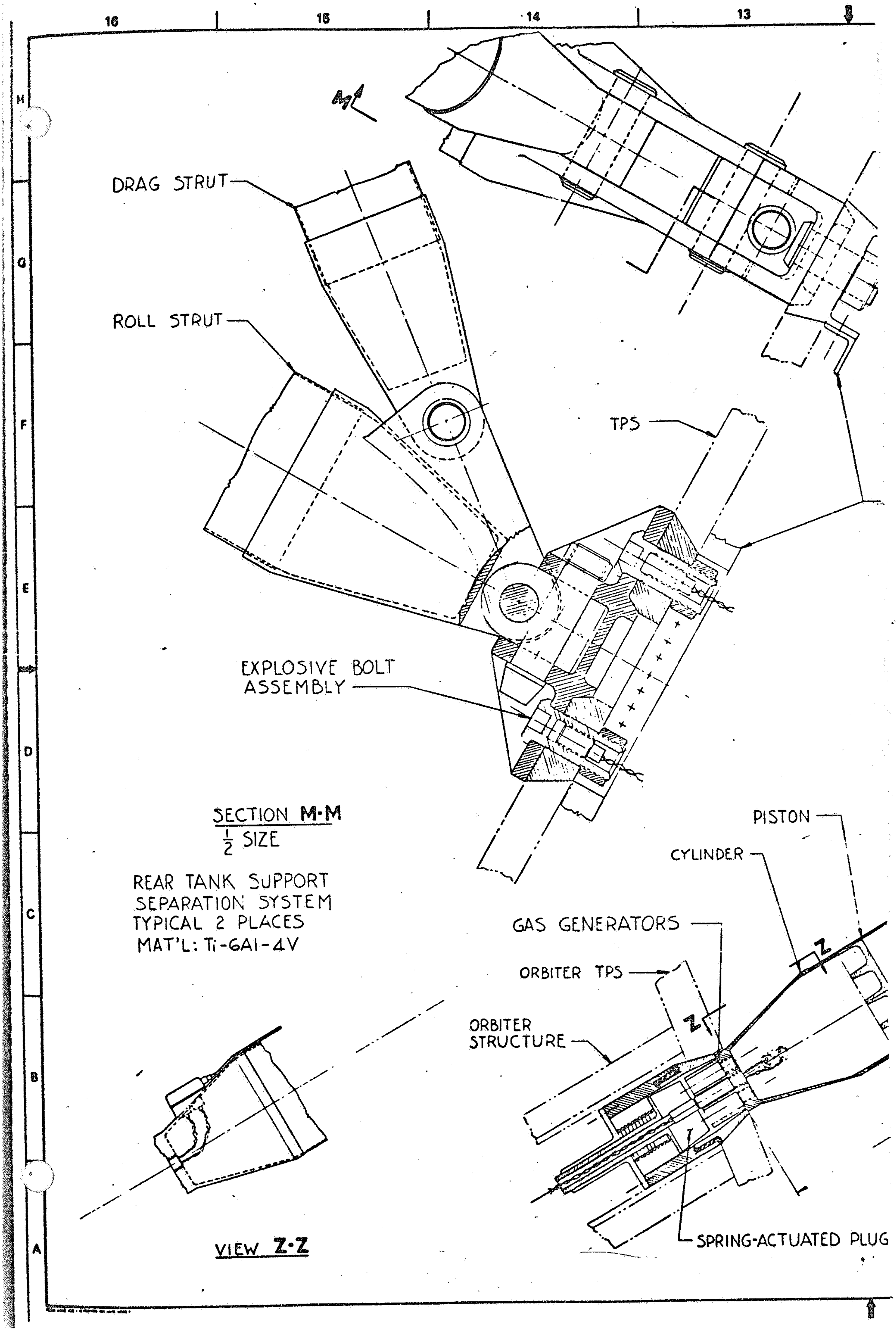
Fig. 17-3 Droptank Assembly, External LH_2 Tank (Sheet 1)



8
7
6
5
4
REAR TA
UPPER
TOP VIEW
TANK ASSEMBLY
EMBLY
SIDE VIEW
REAR
LOWE
ORBITER OML
ILAR TO
CEPT ORIENTATION)
SO
X
BLY
SECTION X-X
VIEW W-W
(ROTATED 90°)



12
11
10
9
M
VIEW E-E
½ SIZE
N
N
ORBITER STRUCTURE
℄ ORBITER
220
TANK FITTING SIMILAR TO
SKS100718 VIEW K
3 PLACES
6.00 DIA
72.0
.040
.040
FRONT TANK SUPPORT AS
MAT'L: Ti-6Al-4V
LOWER TENSION ROD
(TANK END FITTING S
SKS100718 VIEW K
SEPARATION
ORBITER TPS
SQUIB ASSEMBLY
SECTION N-N
FRONT TANK ACTUATOR ASSEMBLY
½ SIZE
SEPARATION SYSTEM
TYPICAL 2 PLACES ON FRONT SUPPORT ASSE
½ SIZE
DRAWING NO
REV
SH



16
15
14
13
H
G
F
E
D
C
B
A
M
DRAG STRUT
ROLL STRUT
TPS
EXPLOSIVE BOLT ASSEMBLY
SECTION M-M
$\frac{1}{2}$ SIZE
REAR TANK SUPPORT
SEPARATION SYSTEM
TYPICAL 2 PLACES
MAT'L: Ti-6Al-4V
PISTON
CYLINDER
GAS GENERATORS
Z
ORBITER TPS
Z
ORBITER STRUCTURE
VIEW Z-Z
SPRING-ACTUATED PLUG

The aft tank-to-orbiter support is accomplished by a pair of V-strut trusses (top and bottom) with the truss apex connected to the orbiter (bulkhead STA 1576) using a U-joint/separation bolt attachment. The strut attachments at the tank are made through clevis joints located at hard points consisting of a pair of I-section rings to react moments induced from drag loads and a pair of intercostals mounted between the I-section rings to transfer the drag load in shear to the tank shell. The forward tank attachment consists of three (3) structural members that resist loads only in the fuselage station plane (lateral loads). The two outboard elements are tension members and the center strut is a tube which resists compression loads and contains one of two tank-deployment actuators (gas generator) mounted inside the strut. The other deployment actuator is located within the orbiter (bulkhead STA 1576) and serves as the shear tie that resists tank loads in the vertical direction (perpendicular to the normal plane of flight). The forward tank structural attach elements are connected to the droptank system through three clevis joints located on a bulkhead in the nose fairing. The other ends of the outboard members are connected to the orbiter fuselage frame system through U-joint/separation bolt attachment devices. The center strut bears against an orbiter-mounted support pad.

17.2 WEIGHTS

The weights for the Grumman tanks were derived in precisely the same manner as described in Section 9 of this report, in the discussion pertaining to the LMSC design weights.

The tank structural weights were developed from the required nominal gage by addition of sheet, forming, and chem-milling tolerances where applicable. To these weights were added the detail calculations for rings, doublers, line-insert penalties and other discontinuitity areas, etc., to arrive at a total weight The ratio of this final weight to the initial weight, based upon nominal gage only, like the LMSC design, came out to be 1.35. This nonoptimum factor was then used as an estimate in deriving the other structural weight items, such as nose fairing and attach structure weights. Equipment support weights were again estimated as being 15 percent of their affected group weights. The main item of interest here is the high penalty associated with the aft structural attach section for the GAC design. This is due to the requirement for attaching the tank at the barrel section calling for the addition of two heavy rings and two longerons distributing the load into the shell.

The baseline insulation system weights are based upon 0.3 in. of cork bonded to the tank wall with 0.75 in. of SOFI on the outer surface. This covers the entire tankage area and lines. The attach struts were covered with 0.30 in. of cork only. The NOF used for this design was 6 percent based upon a full cork and a foam tolerance of +0.275 - 0.00. This was an increase of 1 percent over the tolerance employed for the LMSC design (Section 9) and was meant to account for tolerances on bond, primers, and sealing materials that had not been considered previously. A typical lb-per-ft^2 value buildup of this baseline insulation value would be as follows:

Item	Unit Wt, psf
Tank Wall Primer	0.009
Cork Bond	0.031
0.30 in. Cork @ 30 lb/ft^3	0.750
Cork-to-Foam Bond	0.0864
0.75 in. Foam @ 2 lb/ft^3	0.1250
Foam Sealer Coat	0.500
Σ =	1.0514
Tolerance (NOF) (6%) =	0.0631
TOTAL	1.1145

The attach structure and the plumbing system weights were calculated from the design drawings with estimates added for fittings and supports. The NOF employed was again 35 percent consistent with the derived tank value. The other systems were derived in the same manner as previously discussed in Section 9 of this report. A notable exception is the deorbit system for an assumed, non-tumbling droptank entry at low (nose first) trim angles of attack. For this configuration, only a retrorocket with associated attachments and equipments is assumed. A 10 percent contingency factor is used for reasons previously described in Section 9.

The tabulated weights for the tankage system for the GAC concept are presented in Table 17-1 (The GAC System).

Interestingly enough, it should be noted that the lambda-prime values for all of the tank systems studied fall consistently close enough to a value of 0.813* to insure that within reasonable propellant loading ranges it could serve as an adequate scaling parameter.

17.3 SEPARATION/DEBOOST/ENTRY CONSIDERATIONS

Droptank separation, deboost, and intact entry study results of Sections 4 and 5 are almost directly applicable to the GAC concept because of assumed similarities in geometric and mass property characteristics. In general, droptank separation and deboost sequences would be initiated for entry-to-impact in the Indian Ocean, or for selected missions for impact in the mid-Atlantic. Maximum expected range from separation/retro to impact is of the order of 5000 nm with an assumed nominal retro velocity of 230 fps. Increasing V_R decreases range. Total intrack range dispersions for the nominal case will be from 1500 nm to 2000 nm.

Probably of most importance are the droptank dynamic characteristics as they affect separation and entry design criteria. The separation analysis indicates the necessity of optimizing separation-induced angular rates to separation velocities and minimum separation distance requirements. A maximum pitch rate of 5 deg/sec is compatible with a 35-fps separation velocity and a 2-sec coast before retro fire.

In all cases, it is desirable to provide neutral or minimum aerodynamic stability thereby facilitating a tumbling-flight profile along most of the entry trajectory.

* λ' = Wt Prop/Wt Prop + Wt Tank Inert

Table 17-1

GAC TANK WEIGHTS

ITEM OR CONDITION		WEIGHT (LB)
STRUCTURE GROUP		8,424
Nose Fairing	424	
Fwd Dome and Skirt	216	
Fwd Cone	778	
Cylinder	5,358	
Aft Cone	680	
Equipment Supports	94	
Fwd Attach	128	
Aft Attach	746	
INSULATION		9,518
Nose Fairing	236	
Dome and Skirt	22	
Fwd Cone	1,166	
Cylinder	6,762	
Aft Cone	832	
Struts and Plumbing	500	
SEPARATION SYSTEM		204
DEORBIT SYSTEM		500
PROPULSION SYSTEM		1,474
Feed Press. and Vent	1,224	
Instl. and Power	250	
CONTINGENCY (10 percent)		2,012
DRY WEIGHT		22,132
RESIDUALS (GH_2)		396
RESERVES AND LOSSES		2,656
INERT WEIGHT		25,184
Liquid Hydrogen		120,260
TANK LOADED WEIGHT (TWO)		135,444

Separation-induced angular rates will cause, at least initially, a tumbling, high-drag condition as the tank enters the sensible atmosphere, thereby tending to reduce entry range and dispersions for given retro conditions. However, if tumbling either continuously or partially along the entry trajectory is not practical, droptank design should include a high degree of aero-stability to allow shallow-angle trim conditions for entry (at or near minimum drag). This approach results in TPS weights which are comparable to tumbling tank entry requirements. Consequently, TPS weights established for the GAC concept are representative of a droptank designed for intact entry with either a tumbling flight profile or trimmed to total angles-of-attack below 15 deg. Trimmed entry at angles-of-attack above 25 deg will require TPS weights approximately 50 percent greater than either of the aforementioned conditions.

17.4 MANUFACTURING COST ANALYSIS

The manufacturing cost for the GAC design was established by a cost comparison to the LMSC Configuration B Weld-Bonded concept. A comparative analysis for the design differences and cost considerations is summarized below:

GAC Design Differences From Configuration B	Estimated Increase of Cost, Percent*
Larger Geometry	21
Additional Barrel Sections	22
Additional Strut Structure	200
Additional Instrumentation	5
Increased Cleaning Surface	10
Increased Insulation for Size and Intact Entry	42

In addition to the foregoing, tooling, handling and associated services were increased proportionately. The GAC Manufacturing Cost Summary is shown in Table 17-2.

*Values are not additive.

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GAC MANUFACTURING COST SUMMARY
(RECURRING AND NONRECURRING)

HARDWARE	GAC (000 M/HRS)
TANKS (450 SETS)	23,147
TOOLING AND TEST EQUIPMENT	1,163
TOOLING AND TEST ENGINEERING	387
PLANNING AND OPERATIONS ENGINEERING	2,642
GROUND HANDLING AND LOGISTICS	453
TOTAL MANHOURS	27,792
TRANSPORTATION AND MATERIALS	(000)$
TRANSPORTATION AND PACKAGING	2,298
TOOLING AND TEST EQUIPMENT	4,095
GROUND HANDLING AND LOGISTICS	383
TOTAL DOLLARS	6,776
MACHINERY AND EQUIPMENT	$ 8,215

Table 17-2

Table 17-2

17.5 PROGRAM COSTS

The DDT&E cost for GAC configuration is the same cost figure as developed for LMSC Configuration B. The nonrecurring and recurring costs were derived by using Manufacturing and Product Assurance estimated manhours and material dollars for the GAC configuration. The following dollars were estimated, Tables 17-3 through 17-6.

Table 17-3
TOTAL PROGRAM COSTS

	($ Millions)
NONRECURRING	
DDT&E	$ 58
Production	70
RECURRING	
Production	660
TOTAL	$ 788

Table 17-4
NONRECURRING PRODUCTION COSTS

Manufacturing	$ 54
Product Assurance	2
Raw Materials	4
Special Machinery	10
TOTAL	$ 70

Table 17-5

RECURRING PRODUCTION COSTS

	($ Millions)
Manufacturing	$ 434
Product Assurance	58
Program Management	8
Support Engineering	3
Raw Materials	63
Purchased Components	94
TOTAL	$ 660

Table 17-6

RECURRING MANUFACTURING COSTS

	($ Millions)
Structures Fabrication and Assembly	$ 196
Subsystem Fabrication	78
Subsystem Installation	10
Insulation Application	79
Cleaning	11
Test and Checkout	4
Chemical Processing	2
Rework and Changes	33
Manufacturing Services	21
TOTAL	$ 434

Section 18

NAR CONCEPT

Groundrules and assumptions reflecting lessons learned during Part I and Part II of this study were used to define conceptual droptank arrangements and tank designs based on the available NAR concept definition. General arrangements, insulation concepts and tank structural assembly and associated weights were defined; a manufacturing cost analysis performed; and program costs estimated in the same manner as that used for the well-established baseline Concept B.

18.1 ORBITER/TANK ARRANGEMENT

The general arrangement illustrating the external mounting of the LH_2 droptank system on a reusable orbiter vehicle (North American type concept) is indicated in design drawing SKS 100722 (Fig. 18-1). The external tanks provide for an estimated required volume of approximately 12,900 cu ft each. The overall length of each tank system is approximately 103 ft and was limited by the orbiter bow shock wave at its forward end and the estimated location of the most aft station (thrust structure bulkhead) available for attachment purposes. This restriction resulted in a tank diameter (I.D.) for fourteen (14) ft and, therefore, a tank L/D of 7.35. The structural attach interface stations on the orbiter were assumed on the basis that the forward attach orbiter station would be in the fuselage area where framing would be available for hard point attachments and the aft attach orbiter stations would consist of an aft payload bay fuselage bulkhead and the aforementioned thrust structure fuselage bulkhead.

The droptank system assembly and installation aspects are shown in design drawing SKS 100718 (Fig. 18-2), which identifies the dimensions and locations of plumbing and plumbing equipment for the pressurization, venting, feed, and recirculation lines for the liquid hydrogen tank. The operational instrumentation for temperature, pressure, and liquid level-sensing are also identified and located on this drawing.

Insulation required to protect the tanks for intact entry is indicated and consists of approximately 0.30-in. thick cork bonded directly to the tank system skin surfaces and polyurethane foam sprayed over the cork and machined to provide a foam thickness of approximately 0.75 in. Remaining systems identified are the retrorocket and electrical subsystems. A retrorocket system is installed on the aft end of each tank system and the bulk of the electrical system is installed within the nose fairing. A mechanical/optical separation sensor system employing the use of a tapelike device is included at two places (forward and aft) on each tank. The forward sensor system is installed in the vicinity of the forward attach strut system and the aft sensor system is installed near the retrorocket installation.

The tank assembly shown in this drawing is constructed primarily from 2219-T87 aluminum, using standard sheet stock for the tank skin panels. The assembly consists of a cylinder, forward cone, a forward tank end, and an aft tank end. An aluminum tank skirt is also provided at the forward end of the tank cone. To this skirt is attached a short fairing, constructed from magnesium/wood, which protects the propellant system line-valving associated with the pressurization and venting system, a cluster of tank-dome-mounted temperature sensors, and the bulk of the electrical system equipment.

The method of construction for the tank consists primarily of weld-bonding roll-formed skin panels to a frame system (doublers) fusion-welded (butt joints) together to form a cagelike arrangement in the shape of the desired tank geometry. The details of the tank elements are similar in concept to those described for baseline Configuration B. Section 9.

The aft tank-to-orbiter support is accomplished by a tripod arrangement of struts as shown (Reference Drawing SKS 100722) with the tripod apex connected to the aft end of the droptank system. The outboard struts are primarily

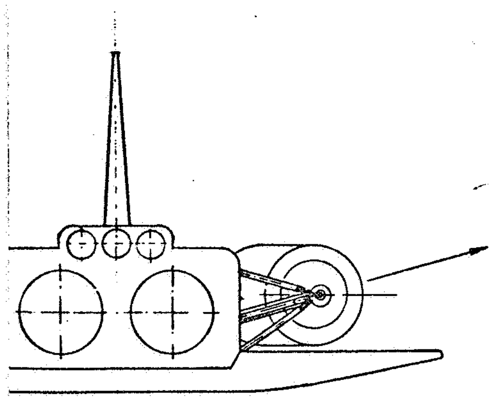
LIMITED CALENDAR LIFE	LIMITED OPERATING LIFE

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APVD

LMSC-A990949

FV



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PARTS LIST

UNLESS OTHERWISE SPECIFIED DIM ARE IN INCHES. TOLERANCES ON:
FRACTIONS = ± 1/16
DECIMALS: .X = ± .1
.XX = ± .03
.XXX = ± .010
ANGLES = ± 2 DEG

CNTR

A/CI/FD

DATE 6-16-71
DWN H. Schmidt
APVD
APVD
ENGRG
CHKR
APVD
APVD

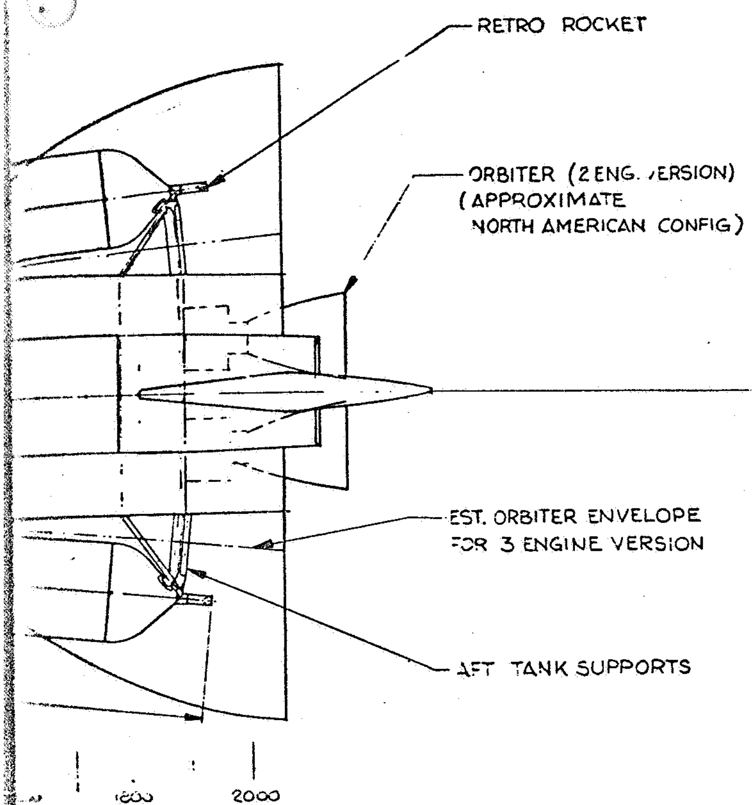
LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

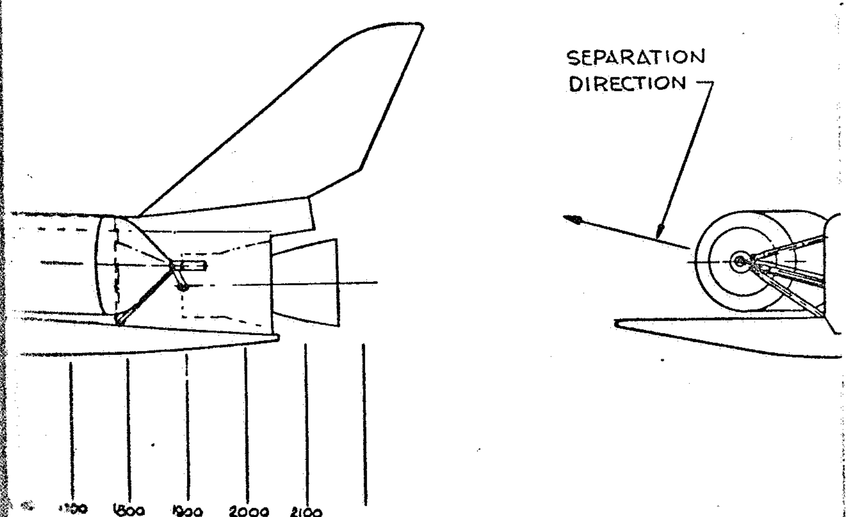
GENERAL ARRANGEMENT
EXTERNAL LH_2 TANK
NORTH AMERICAN ORBITER

SIZE	CODE IDENT	DRAWING NO	REV
E	06337	LSAS 100722	–

SCALE 1/100 SHEET

4 3





NOTES :

1. FOR SEPARATION STRUT DETAILS SEE DWG. SKG 100719
2. FOR TANK ASSY. DETAILS SEE DWG. SKS 100718

QTY REQD	CODE IDENT

INTERPRET DWG PER

NEXT ASSY	USED ON
APPLICATION	

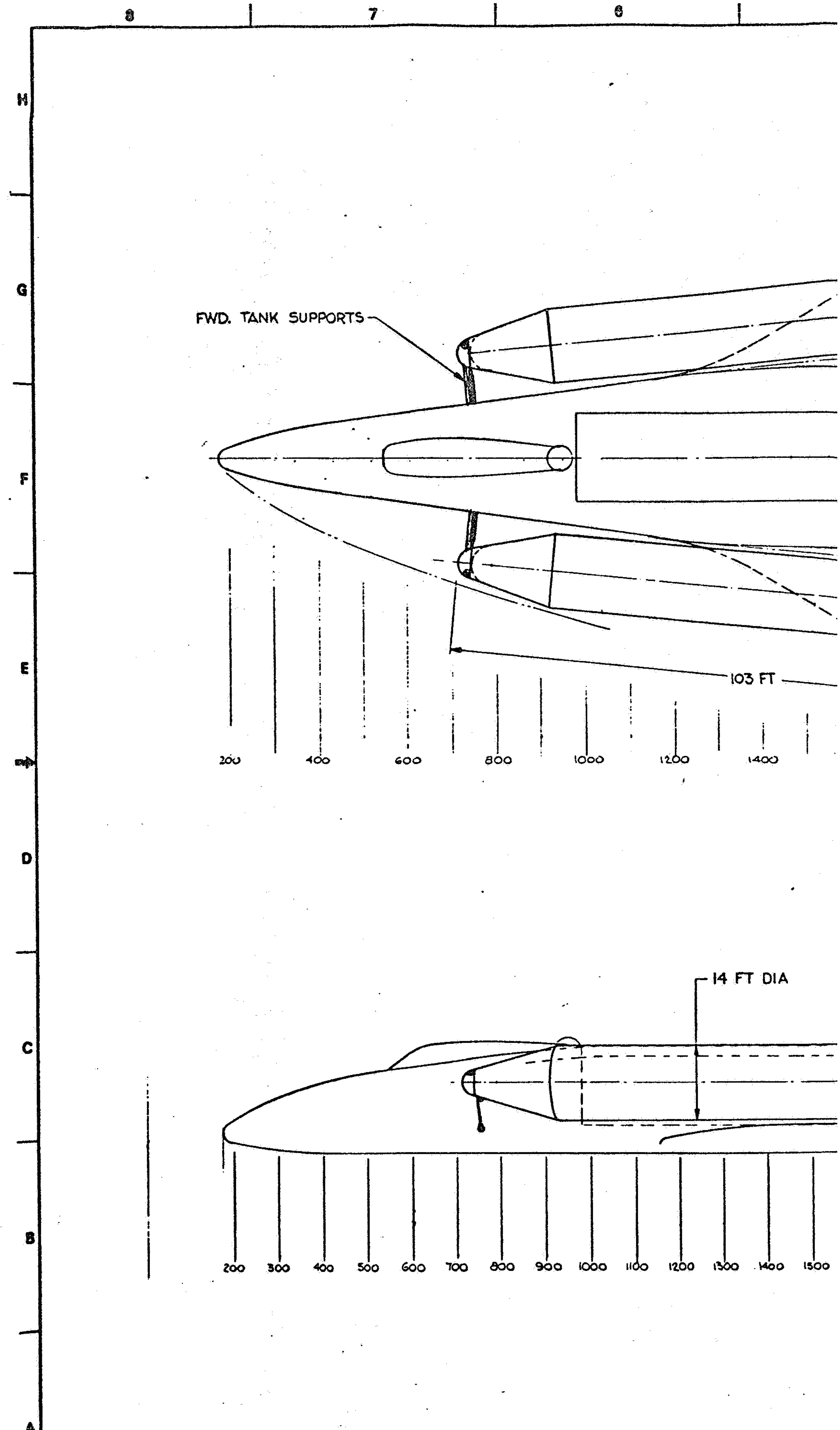


Fig. 18-1 General Arrangement, Exte

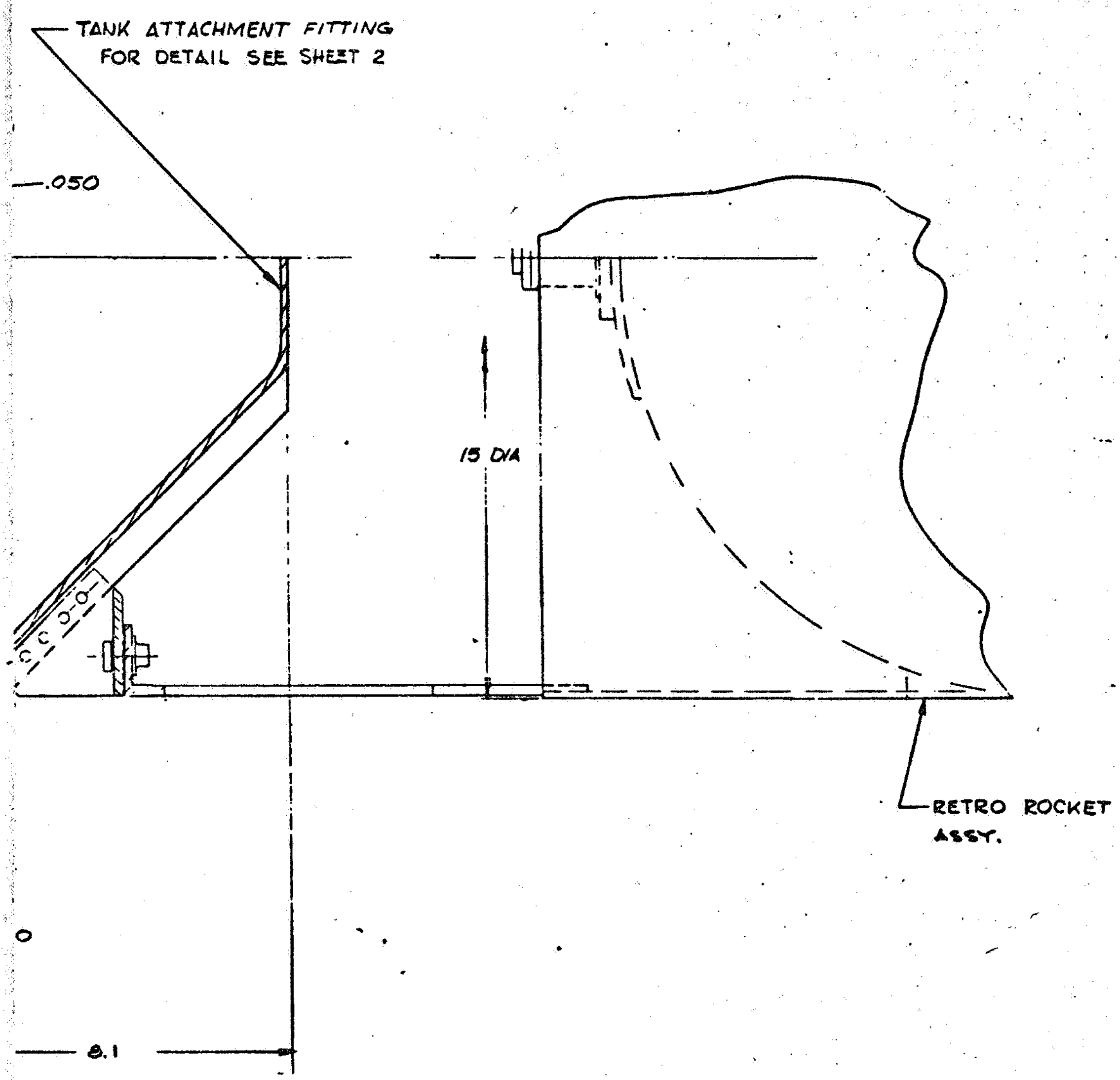


Fig. 18-2 Droptank Assembly and Installation (Sheet 1)

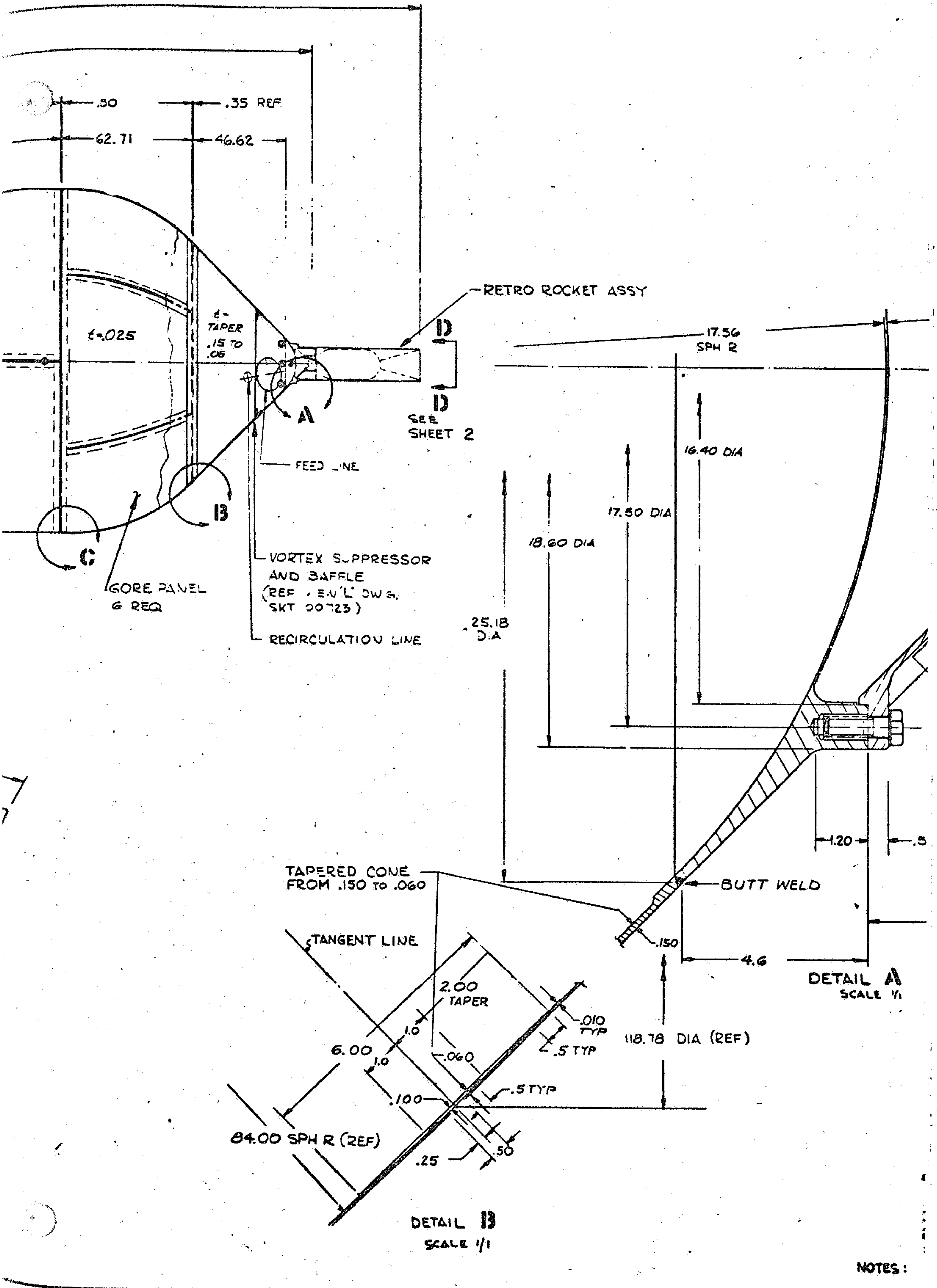
6. INSTRUMENTATION SIMILAR TO DWG. SKT 100723
5. APPLY TO EXTERAL SURFACES: ONE COAT 3547 CHEMSEAL AND ONE COAT V455 DYNA THERM PAINT.
4. ALUMINUM ALLOY PARTS FORMED BY SPINNING ARE 2219-T81
3. TANK VOL.: 10,885 FT^3
2. REF. DWG. SKS 100722
1. TANK MAT'L. 2219-T87 AL ALLOY EXCEPT AS SHOWN OTHERWISE.

MISSILES & SPACE COMPANY
SUNNYVALE, CALIFORNIA

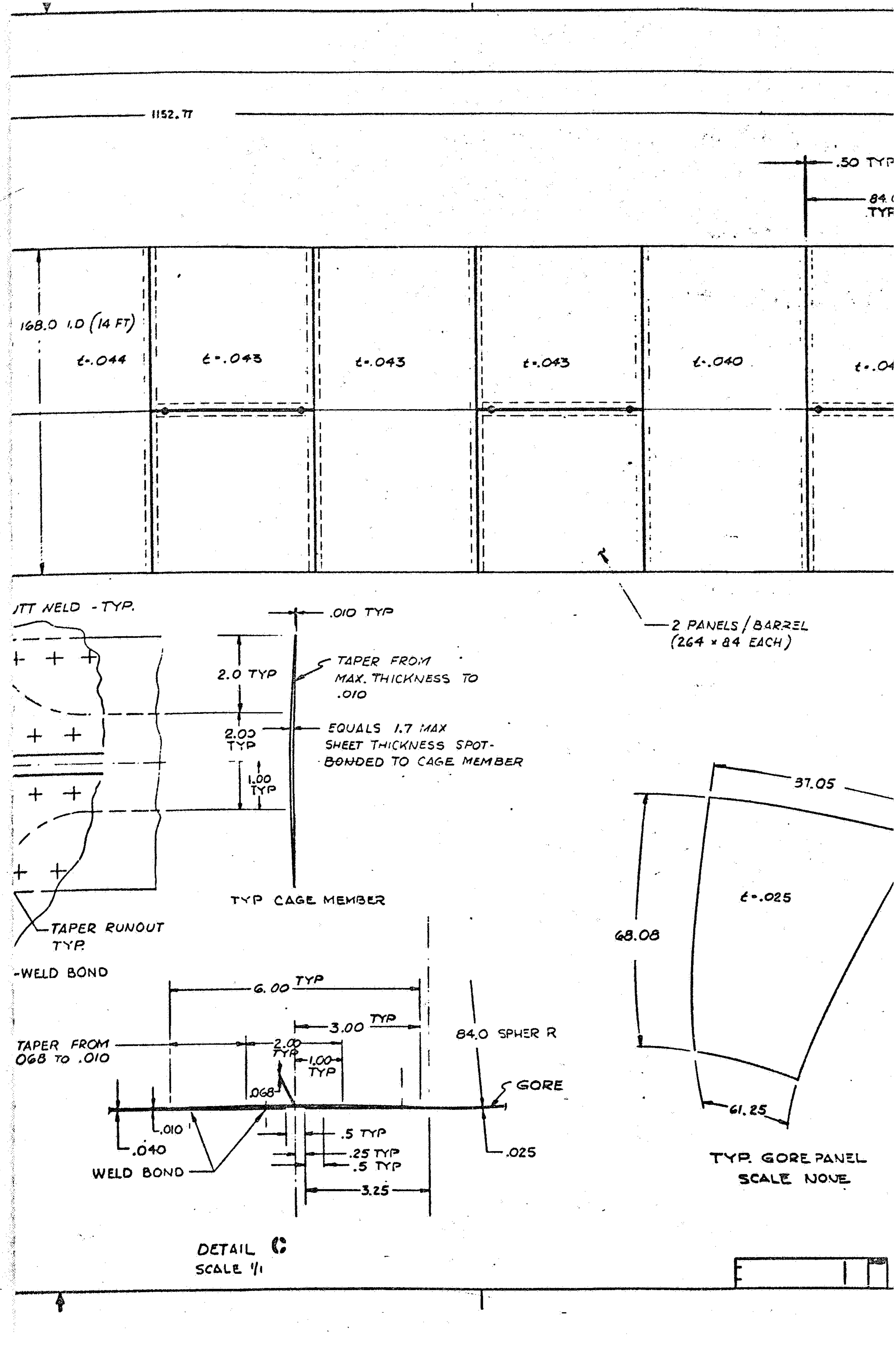
DATE 6-15-71

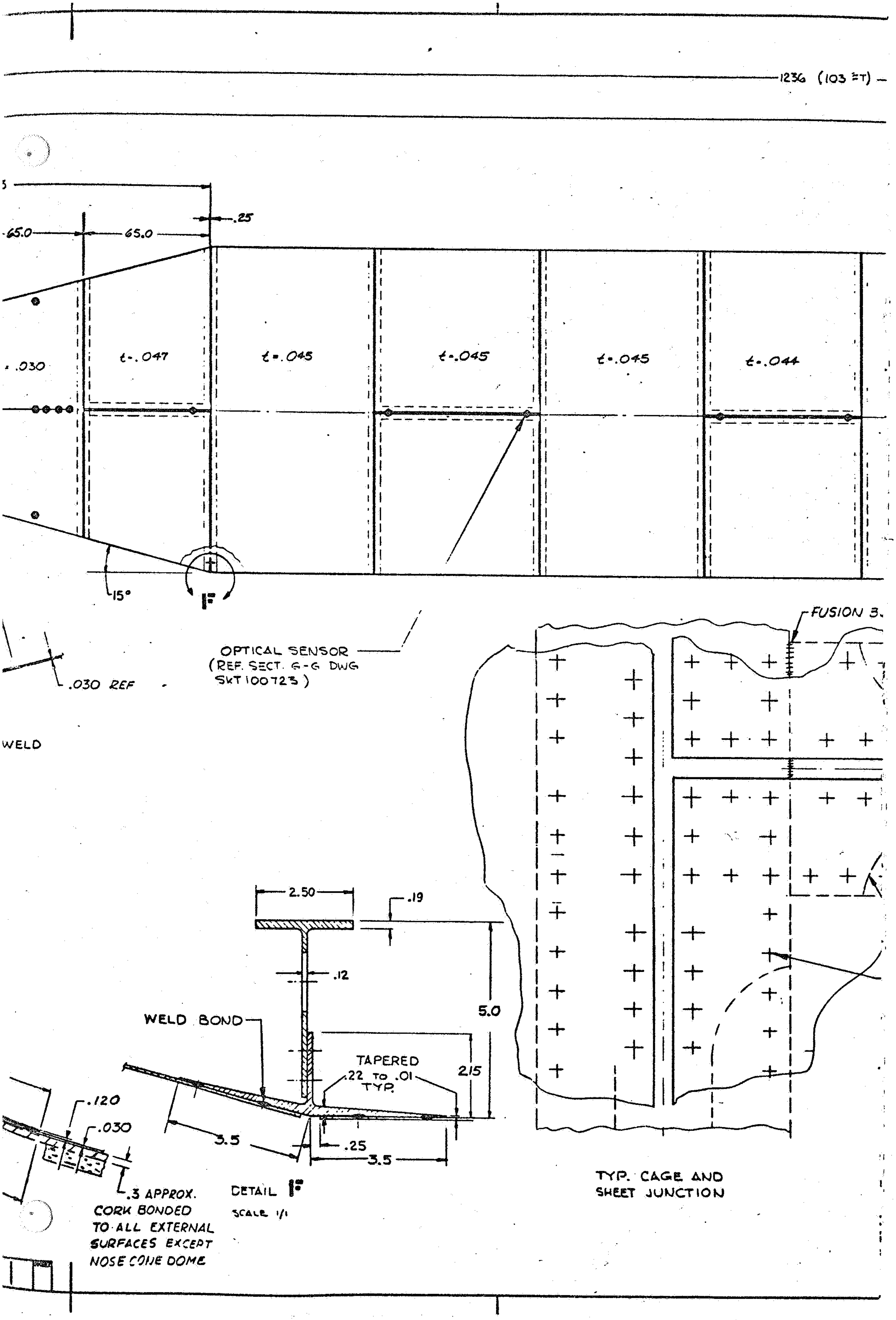
DROP TANK ASSEMBLY
EXTERNAL LH_2 TANK
(NORTH AMERICAN ORBITER)

06887 J SKS 100718

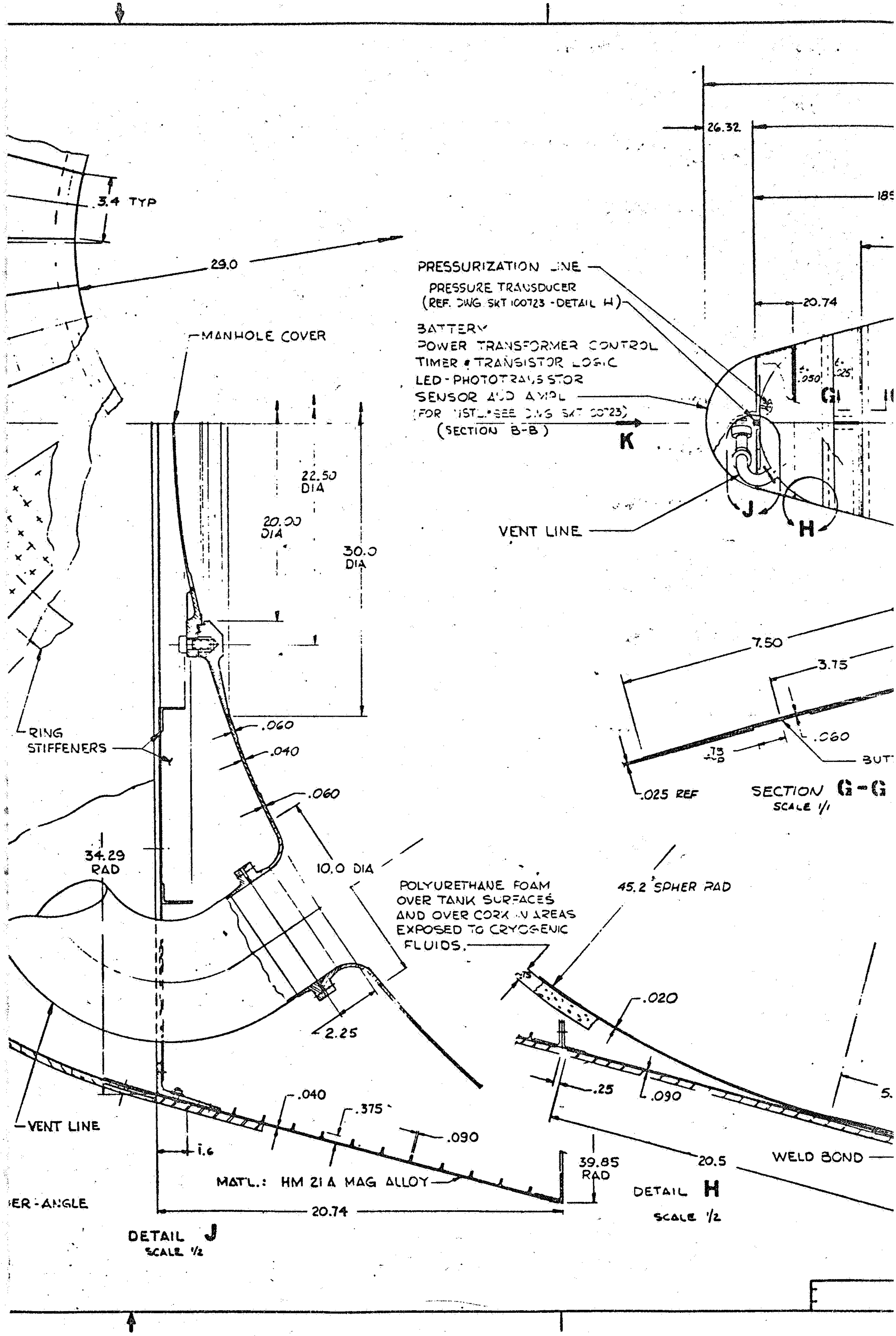


.50
.35 REF.
62.71
46.62
t=.025
t= TAPER .15 TO .06
RETRO ROCKET ASSY
D
D
SEE SHEET 2
A
B
C
FEED LINE
VORTEX SUPPRESSOR AND BAFFLE (REF ENG'L DWG. SKT 00723)
GORE PANEL 6 REQ
RECIRCULATION LINE
17.56 SPH R
16.40 DIA
17.50 DIA
18.60 DIA
25.18 DIA
1.20
.5
BUTT WELD
TAPERED CONE FROM .150 TO .060
.150
4.6
DETAIL A
SCALE 1/1
118.78 DIA (REF)
TANGENT LINE
2.00 TAPER
.010 TYP
.5 TYP
1.0
1.0
6.00
.060
.5 TYP
.100
84.00 SPH R (REF)
.25
.50
DETAIL B
SCALE 1/1
NOTES:

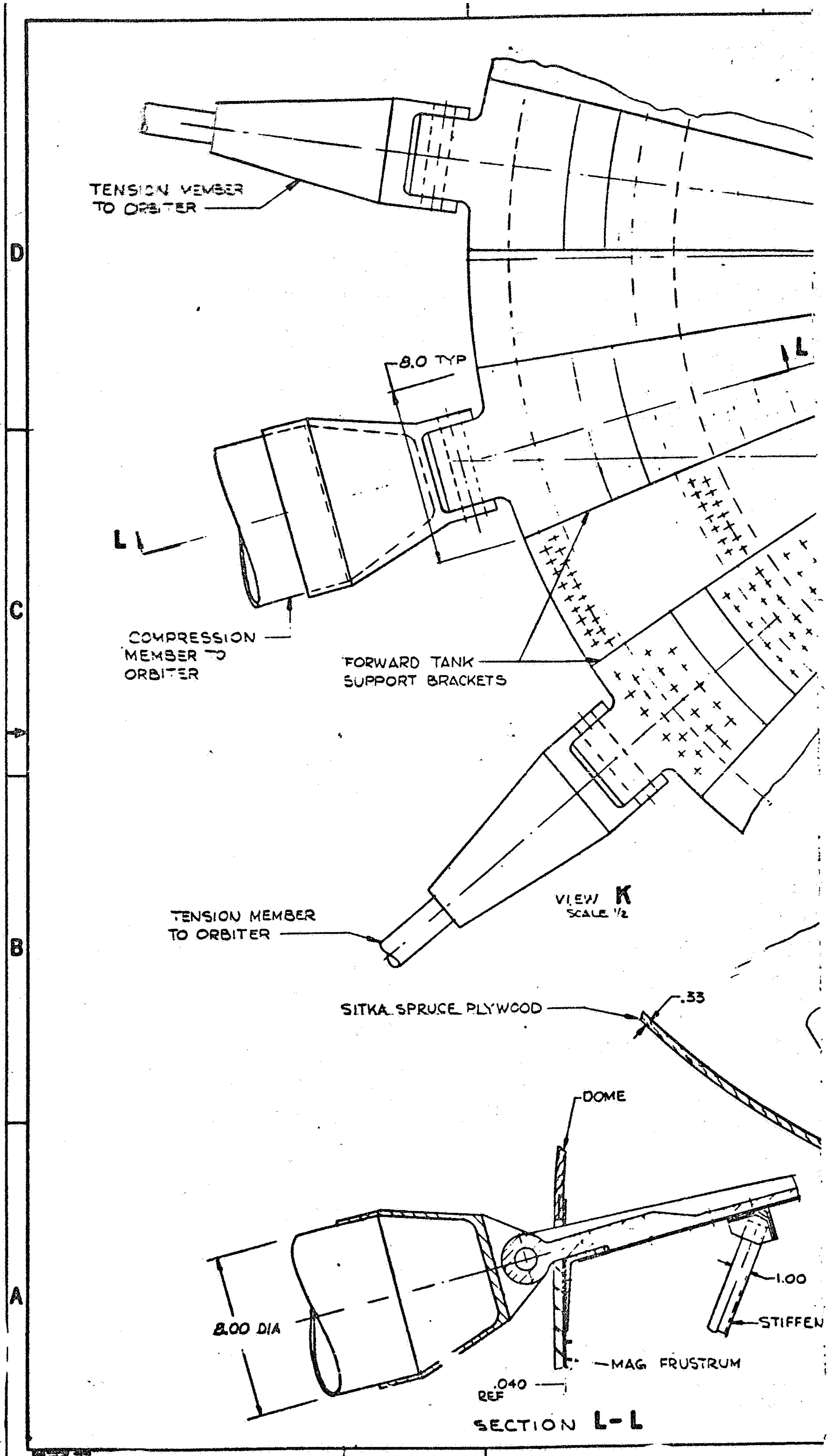

1152.77
.50 TYP
84.0 TYP
168.0 I.D (14 FT)
t-.044
t-.043
t-.043
t-.043
t-.040
2 PANELS / BARREL
(264 × 84 EACH)
TT WELD - TYP.
.010 TYP
2.0 TYP
TAPER FROM MAX. THICKNESS TO .010
2.00 TYP
EQUALS 1.7 MAX SHEET THICKNESS SPOT-BONDED TO CAGE MEMBER
1.00 TYP
TYP CAGE MEMBER
TAPER RUNOUT TYP.
-WELD BOND
37.05
68.08
t-.025
61.25
TYP. GORE PANEL
SCALE NONE
6.00 TYP
3.00 TYP
84.0 SPHER R
TAPER FROM .068 TO .010
2.00 TYP
1.00 TYP
.068
GORE
.010
.040
WELD BOND
.5 TYP
.25 TYP
.5 TYP
3.25
.025
DETAIL C
SCALE 1/1



1236 (103 FT)
65.0
65.0
.25
.030
t-.047
t-.045
t-.045
t-.045
t-.044
15°
F
OPTICAL SENSOR
(REF. SECT. G-G DWG
SKT 100723)
.030 REF
WELD
FUSION
2.50
.19
.12
5.0
WELD BOND
TAPERED
.22 TO .01
TYP.
2.15
.120
.030
3.5
.25
3.5
.3 APPROX.
CORK BONDED
TO ALL EXTERNAL
SURFACES EXCEPT
NOSE CONE DOME
DETAIL F
SCALE 1/1
TYP. CAGE AND
SHEET JUNCTION



26.32
185
3.4 TYP
29.0
PRESSURIZATION LINE
PRESSURE TRANSDUCER
(REF. DWG SKT 100723 - DETAIL H)
BATTERY
POWER TRANSFORMER CONTROL
TIMER & TRANSISTOR LOGIC
LED-PHOTOTRANSISTOR
SENSOR AND AMPL
(FOR INSTL-SEE DWG SKT 100723)
(SECTION B-B)
20.74
.050
.025
G
K
J
H
MANHOLE COVER
22.50 DIA
20.00 DIA
30.0 DIA
VENT LINE
7.50
3.75
.060
.025 REF
SECTION G-G
SCALE 1/1
RING STIFFENERS
.060
.040
.060
10.0 DIA
34.29 RAD
POLYURETHANE FOAM OVER TANK SURFACES AND OVER CORK IN AREAS EXPOSED TO CRYOGENIC FLUIDS.
45.2 SPHER RAD
.020
2.25
.25
.090
.040
.375
.090
VENT LINE
1.6
MAT'L.: HM 21 A MAG ALLOY
39.85 RAD
20.5
WELD BOND
DETAIL H
SCALE 1/2
ER-ANGLE
20.74
DETAIL J
SCALE 1/2



TENSION MEMBER
TO ORBITER
D
8.0 TYP
L
L
C
COMPRESSION
MEMBER TO
ORBITER
FORWARD TANK
SUPPORT BRACKETS
VIEW K
SCALE 1/2
B
TENSION MEMBER
TO ORBITER
SITKA SPRUCE PLYWOOD
.33
DOME
A
1.00
8.00 DIA
STIFFEN
MAG FRUSTRUM
.040
REF
SECTION L-L

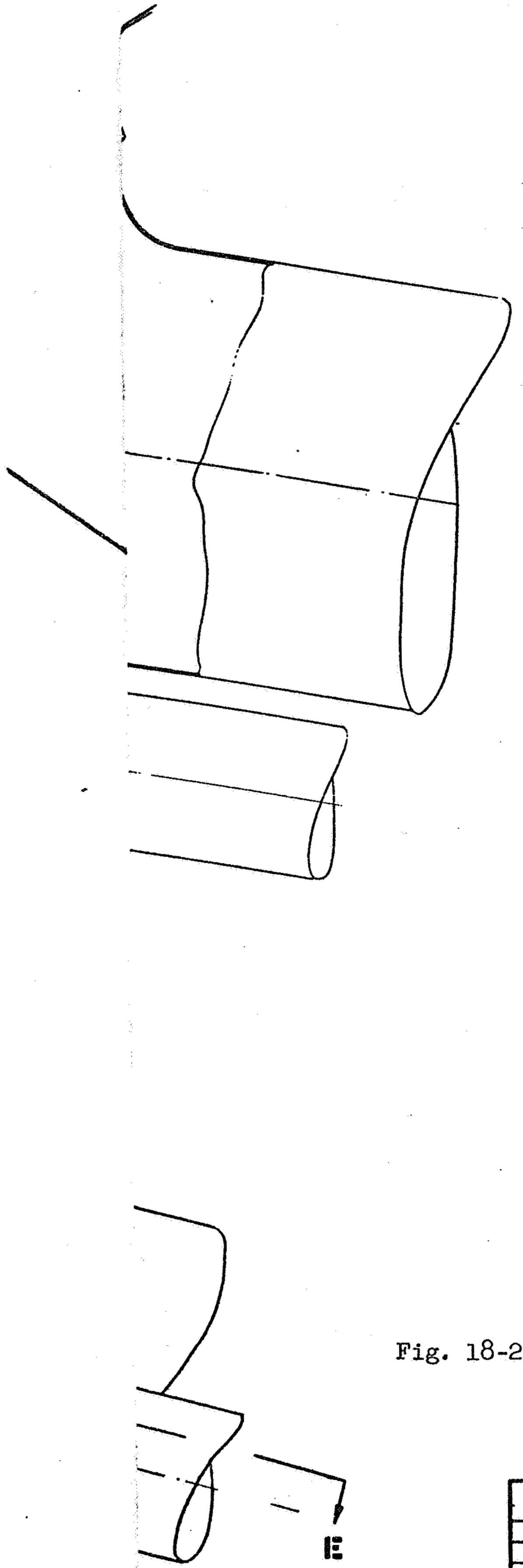


Fig. 18-2 Droptank Assembly and Installation (Sheet 2)

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL DESCRIPTION OR NOTE	MATERIAL SPECIFICATION	ZONE	ITEM NO.

PARTS LIST

INTERPRET DWG PER

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED DIM. ARE IN INCHES TOLERANCES ON:
FRACTIONS = ± 1/16
DECIMALS: .X = ± .1
.XX = ± .03
.XXX = ± .010
ANGLES = ± 2 DEG

CONTR

CCA/CEI

DATE

DR

APPD

APPD

ENGRG

CHK

APPD

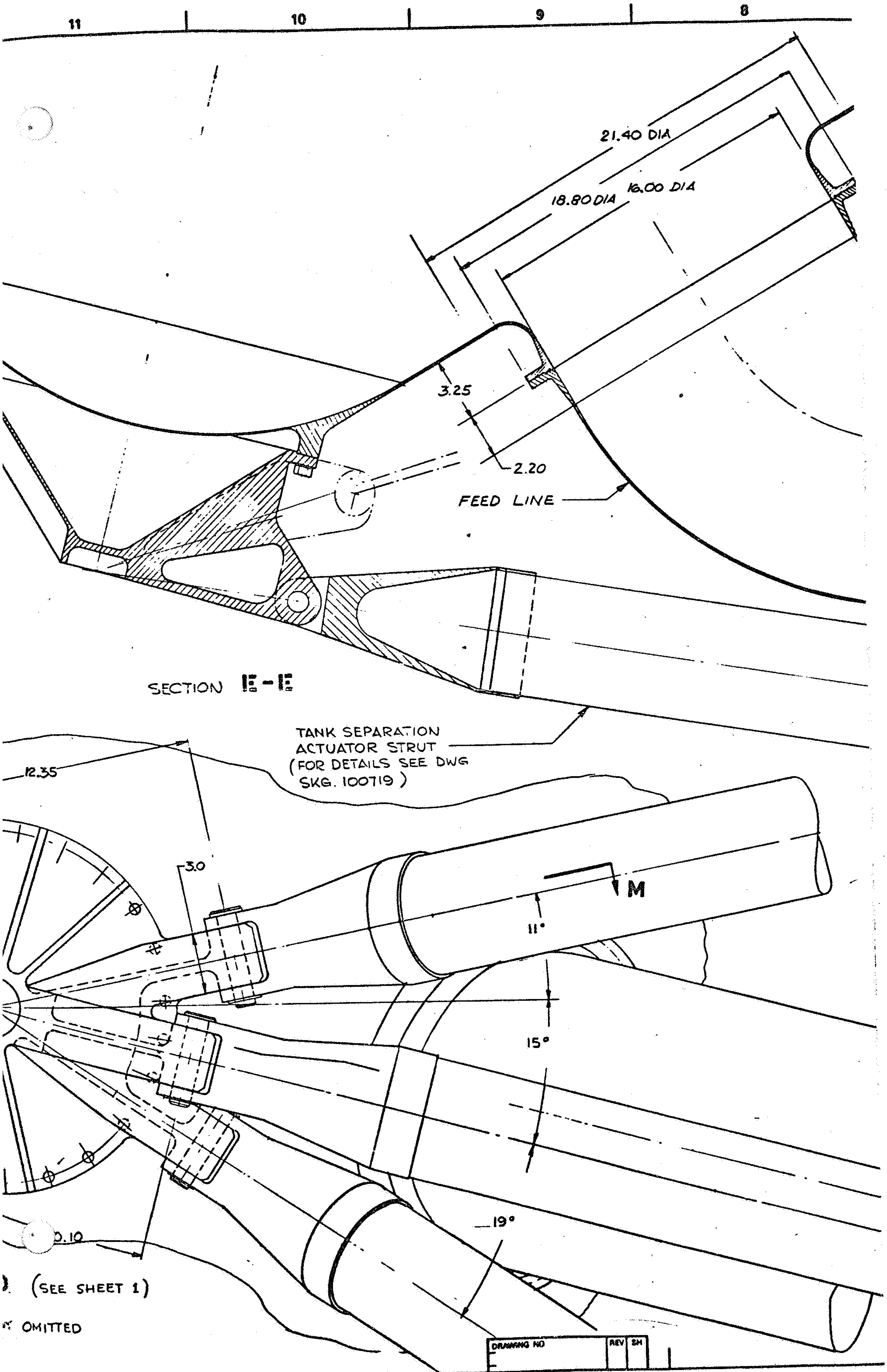
APPD

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

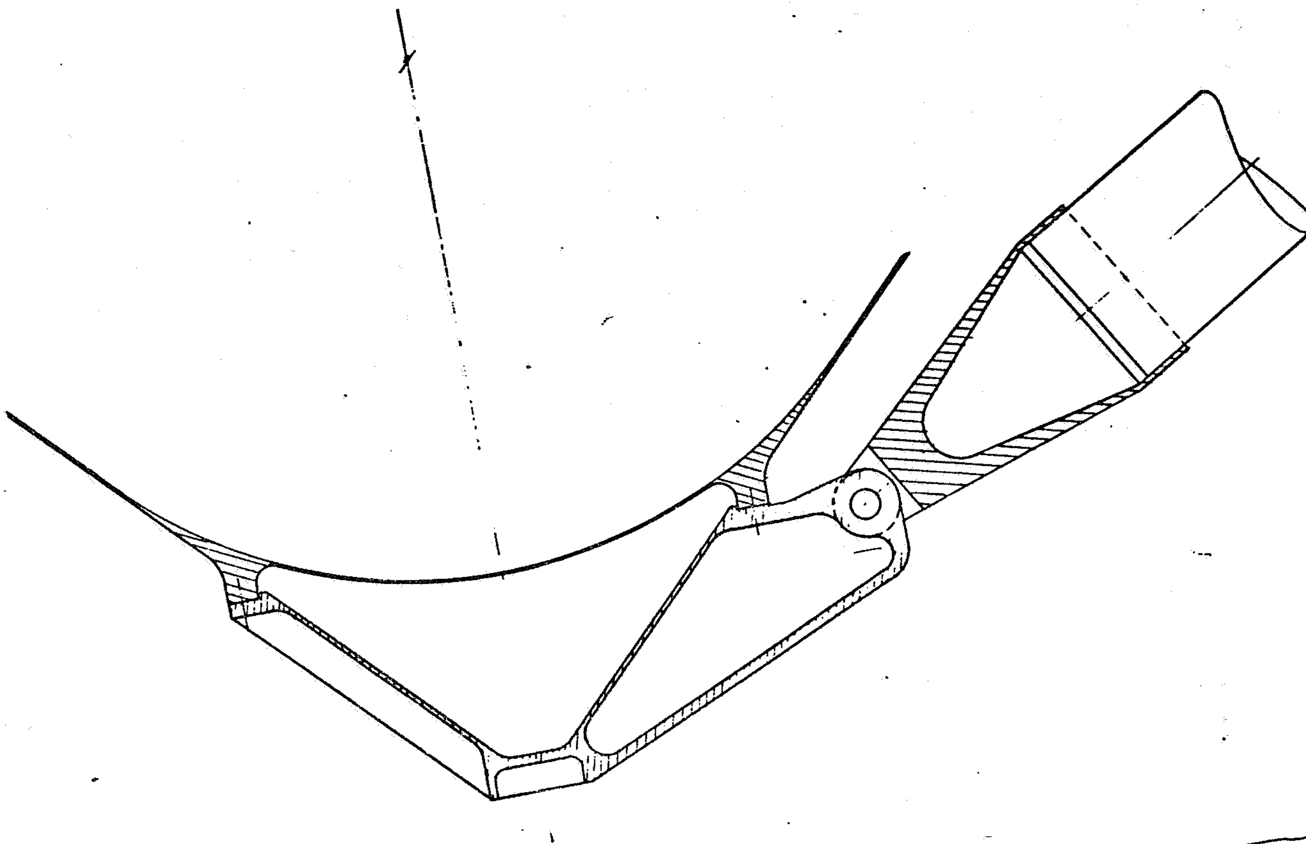
DROP TANK ASSEMBLY
EXTERNAL LH_2 TANK
(NORTH AMERICAN ORBITER)

SIZE | CODE IDENT 06937 | DRAWING NO. S/S 100718 | REV

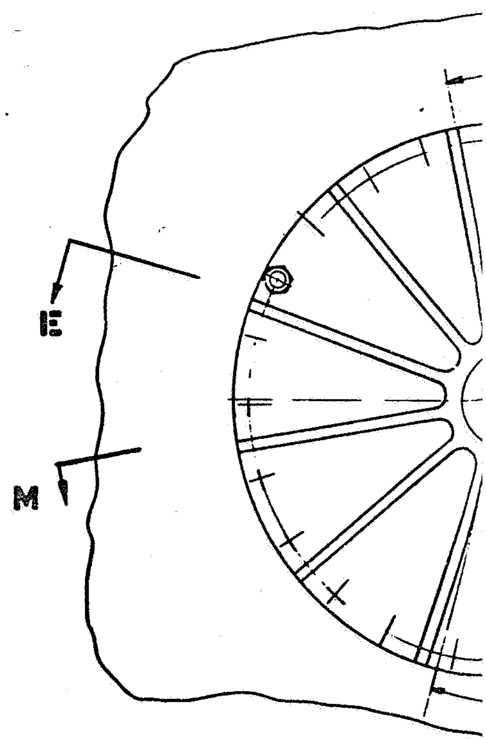
SCALE | SHEET



11
10
9
8
21.40 DIA
18.80 DIA
16.00 DIA
3.25
2.20
FEED LINE
SECTION E-E
TANK SEPARATION
ACTUATOR STRUT
(FOR DETAILS SEE DWG
SKG. 100719)
12.35
3.0
M
11°
15°
19°
0.10
(SEE SHEET 1)
OMITTED
DRAWING NO
REV
SH



SECTION M-M



VIEW D-
SCALE 1/2
(RETRO ROCKET
FOR CLARITY

tension-oriented drag braces, while the center strut takes compression loads and contains the aft tank deployment actuator (gas generator).

The forward tank attachment consists of three (3) structural members that resist loads only in the fuselage station plane (lateral loads). The two outboard elements are tension members and the center strut is a tube which resists compression loads and contains the forward tank deployment actuator (gas generator).

18.2 WEIGHTS

The weights presented in Table 18-1 reflect a 10,464-lb Dry Weight for the NAR LH_2 droptank shown in Dwg. SFS 100718. These weights were developed and reported in the same manner as the GAC LH_2 droptank presented in Section 17 and Configuration B, Section 9.

18.3 SEPARATION/DEBOOST/ENTRY CONSIDERATIONS

Because of the general similarity of NAR droptank geometry and mass properties to the baseline configuration, design considerations for separation/deboost/ entry conditions are comparable to those discussed in Section 17.3 for the GAC concept.

18.4 MANUFACTURING COST ANALYSIS

The manufacturing cost for the NAR design was evaluated in the same manner as the GAC design. The comparison to the LMSC Configuration B and resulting differences are as follows:

NAR Design Difference from Configuration B	Estimated Increase* of Cost (%)
Additional Length	33
Additional Barrel Sections	30
Additional Instrumentation	5
Increased Cleaning Surfaces	30
Increased Insulation for Size and Intact Entry	42

*Values are not additive

Table 18-1

NAR TANK WEIGHTS

Item or Condition		Weight (lb)
Structure Group		7,636
Nose Fairing	402	
Fwd. Dome & Skirt	208	
Fwd. Cone	622	
Cylinder	5,198	
Aft Cone	700	
Equipment Supports	98	
Fwd. Attach	118	
Aft Attach	290	
Insulation		9,362
Nose Fairing	222	
Dome & Skirt	20	
Fwd. Cone	976	
Cylinder	6,890	
Aft Cone	724	
Struts & Plumbing	530	
Separation System		170
Deorbit System		500
Propulsion System		1,358
Feed Press. & Vent	1,108	
Instr. & Power	250	
Contingency (10%)		1,902
Dry Weight		20,928
Residuals (GH_2)		372
Reserves & Losses		2,486
Inert Weight		23,786
Liquid Hydrogen		103,306
Tank Loaded Weight (Two)		127,092

In addition to the increase in tank hardware, tooling, handling, and associated services were increased proportionately. The NAR manufacturing cost summary is shown in Fig. 18-3. In order to show complete and equitable program costs, transportation machinery, ground handling, logistics, and associated services were costed into the GAC and NAR program using the LMSC Concept B costs.

18.5 PROGRAM COSTS

North American cost for DDT&E is the same cost figure as developed for LMSC Configuration B. The nonrecurring and recurring costs were derived by using Manufacturing and Product Assurance estimated manhours and material dollars for the North American configuration. The following dollars were estimated in Tables 18-2 through 18-5.

Table 18-2

TOTAL PROGRAM COSTS

	($ Millions)
Nonrecurring	
DDT&E	$ 58
Production	69
Recurring	
Production	635
Total	$ 762

Table 18-3

NONRECURRING PRODUCTION COSTS

Manufacturing	$ 53
Product Assurance	2
Raw Materials	4
Special Machinery	10
Total	$ 69

Table 18-4

RECURRING PRODUCTION COSTS

	($ Millions)
Manufacturing	$ 412
Product Assurance	55
Program Management	8
Support Engineering	3
Raw Materials	63
Purchased Components	94
Total	$ 635

Table 18-5

RECURRING MANUFACTURING COST

	($ Millions)
Structures Fabrication & Assembly	$ 174
Subsystem Fabrication	76
Subsystem Installation	10
Insulation Application	79
Cleaning	13
Test & Checkout	4
Chemical Processing	1
Rework and Change	34
Manufacturing Services	21
Total	$ 412

LOCKHEED

NAR MANUFACTURING COST SUMMARY
(RECURRING AND NONRECURRING)

HARDWARE	NAR (000 M/HRS)
TANKS (450 SETS)	21,882
TOOLING AND TEST EQUIPMENT	1,238
TOOLING AND TEST ENGINEERING	390
PLANNING AND OPERATIONS ENGINEERING	2,523
GROUND HANDLING AND LOGISTICS	453
TOTAL MANHOURS	26,486
TRANSPORTATION AND MATERIALS	(000)$
TRANSPORTATION AND PACKAGING	2,298
TOOLING AND TEST EQUIPMENT	4,208
GROUND HANDLING AND LOGISTICS	383
TOTAL DOLLARS	6,889
MACHINERY AND EQUIPMENT	$ 8,215

Fig. 18-3

Fig. 18-3

Section 19
McDONNELL-DOUGLAS TANK COST

The latest available configuration of the MDAC external hydrogen tanks was costed using the Lockheed CERs described in Section 22. All physical data for the tank design and weights were obtained from the MDAC External Tank Study, Third Status Report, dated 25 May 1971. It was assumed that the MDAC tank structure was of monocoque aluminum construction and used the fusion-weld technique in the manufacturing process. Apparently, the MDAC design corresponds to Concept A of the current Lockheed study. Therefore, the cost estimates were based on the existing Lockheed CERs for recurring cost and the revised Lockheed CERs for nonrecurring costs which are discussed in Section 22. For recurring costs, a learning rate of 92 percent was postulated, the same rate as used in arriving at the CER estimate for the recurring costs of the Lockheed Concept A.

The MDAC data show a weight breakdown including contingency for one tank (less deorbit system) as follows:

Structure	14,967 lb
Insulation and other	6,534 lb
Total	21,501 lb

The Lockheed CER for Theoretical First Unit (TFU) cost is,

$$\text{TFU} = (5.95 \times 10^3)(\text{Weight per tank})^{.607}\ (F_c)$$

when F_c is the overall complexity factor for material and type of construction. The same individual factors that applied in Concept A for structure and for insulation and others were used. These are: 0.6 for the aluminum monocoque structure and 1.0 for insulation and others. Then the overall complexity factor for the tank is,

$$F_c = \frac{(0.6)(14,967) + (1.0)(6,534)}{21,501} = \frac{8,980 + 6,534}{21,501} = .722.$$

Then:

$$TFU = (5.95 \times 10^3)(21,501)^{.607} (.722)$$

$$TFU = (5.95 \times 10^3)(4.264 \times 10^2)(.722)$$

$$TFU = 1.832 \text{ \$ million.}$$

Recurring costs for the tanks less deorbit systems are then,

$$C_R = (1.832)(1.224)(451) = 1,011 \text{ \$ million}$$

where the term 1.224 is the factor for support at 11.3 percent and fee at 10 percent and the term 451 is the learning factor for 900 tanks at 92 percent learning.

Total recurring cost for the tanks is arrived at by adding $15 million, the Lockheed detailed estimate for the deorbit system of Concept A. The estimate for the MDAC deorbit system may be somewhat light since the MDAC tanks are heavier than the Concept A tanks and should require more or larger solid rockets to achieve the same retro-velocity. However, since the deorbit system appears to be a small percentage of the total cost, this effect was ignored.

The Lockheed CER estimate for 900 MDAC tanks is therefore $1,011 plus $15 million, or $1,026 million.

Nonrecurring costs were computed using the Lockheed CER as revised to fit the detailed estimates of Concepts A, B, and C. That is,

$$C_{DDT\&E} = \left[(4.54)(\text{Weight of Tank Set})^{.312} + (7)(\text{TFU})\right][1.224]$$

$$C_{DDT\&E} = \left[(4.54)(44{,}982)^{.312} + (7)(1.832)\right][1.224]$$

$$C_{DDT\&E} = \left[(4.54)(28.3) + (7)(1.832)\right][1.224] \quad \$ \text{ million}$$

$$C_{DDT\&E} = \$173 \text{ million.}$$

Total program costs for the MDAC tanks as estimated by Lockheed CERs are therefore:

Nonrecurring (DDT&E)	$ 173 million
Recurring	1,026 million
Total	$1,199 million

Section 20

SUMMARY OF APPLICATION STUDY

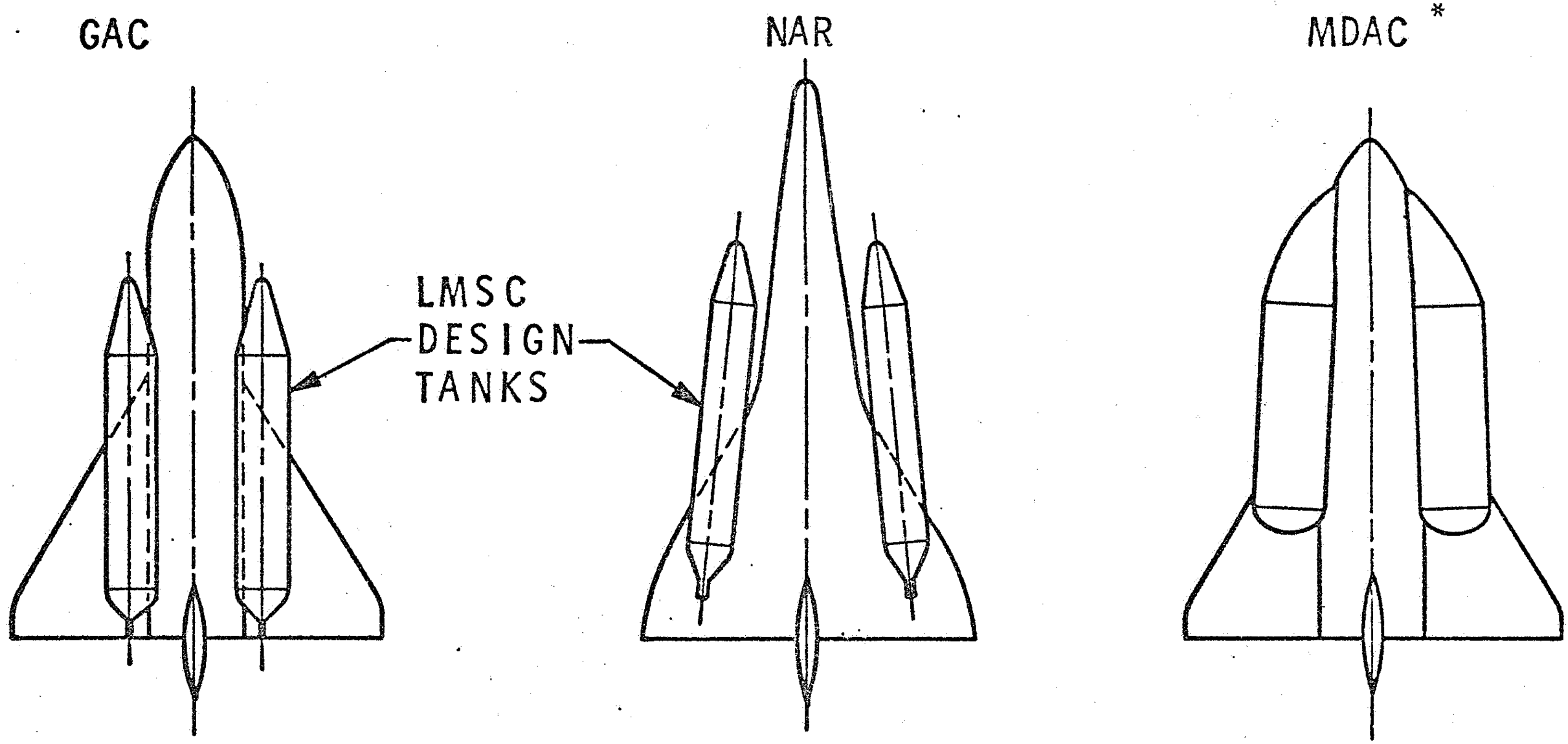
Initially, design studies were made and their results analyzed to determine the most promising tank concept for use as a baseline. After determination of this baseline, it was then applied to alternate tank designs suitable for use with other shuttle configurations (shuttle designs of other contractors, i.e., Grumman (GAC), North American (NAR), etc.). This section presents the major results of the Part III Application Study which produced tank designs for both the GAC and NAR orbiters. These results are shown in Fig. 20-1 and Table 20-1.

Figure 20-1 illustrates the basic tank configurations and gives the diameter, length, volume, and structural weight for each. The values shown for GAC and NAR were derived from the LMSC-designed tanks (see Sections 17 and 18), while the values shown for MDAC are those published by McDonnell-Douglas in their Third Status Report - External Tank Study, 25 May 1971.

Table 20-1 provides the total tank system weights and program costs for each peculiar design configuration. The weights and costs shown for both GAC and NAR are bottom-up compilations based on detailed designs, manufacturing analyses, and development considerations. The weight shown for the MDAC tank is that published in their Third Status Report - External Tank Study, 25 May 1971. Using this MDAC weight and the LMSC cost-estimating relationship (CER) developed for droptanks, a DDT&E cost and a recurring production cost were determined for the MDAC design.

LOCKHEED

TANK/ORBITER ASSEMBLY - LMSC



	GAC	NAR	MDAC *
TANK DIA	15 FT	14 FT	21.5 FT
TANK LENGTH	98.3 FT	103 FT	105.3 FT
TANK VOLUME	13,666 FT^3	12,804 FT^3	28,500 FT^3
TANK STRUCTURE WEIGHT	3,516 LB	3,364 LB	13,606 LB

Fig. 20-1

D03892 * McDonnel-Douglas Company, Third Status Report - External Tank Study, 25 May 1971.

Fig. 20-1

DROPTANK DESIGN APPLICATION STUDY RESULTS

MAJOR PROGRAM PARAMETERS	TANK DESIGN		
	ALUMINUM, WELD-BONDED		ALUMINUM, FUSION-WELDED
	GRUMMAN	NORTH AMERICAN	MCDONNELL/DOUGLAS
TOTAL TANK WEIGHT	22,132 LB	20,928 LB	44,982 LB*
DDT&E COSTS	$128M	$127M	$171M**
RECURRING PRODUCTION COSTS	$660M	$635M	$1197M**
TOTAL TANK COST	$788M	$762M	$1368M

* PER MCDONNELL-DOUGLAS COMPANY THIRD STATUS REPORT – EXTERNAL TANK STUDY, 25 MAY 1971

** DETERMINED BY LMSC CER

D03553

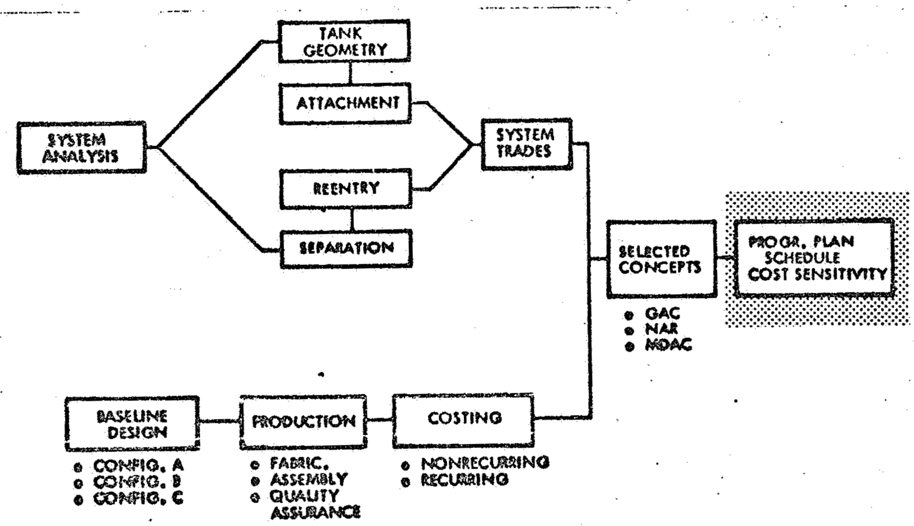
Table 20-1

PART IV

Part IV

PROGRAM SUMMARY

Part IV describes the results of the study activities highlighted in the figure below. It describes a typical program plan and program schedule for the development and production of droptanks for external tank orbiter configurations, gives cost sensitivities to changes of program size, and relates costing results to CERs and droptank estimates from other studies.



Section 21
DROPTANK PROGRAM PLAN

A primary objective of the Alternate Concepts Study, Contract NAS 8-26362 has been to establish a workable program plan for developing and producing an External LH_2 Droptank System based upon the most cost-effective system design variation and associated manufacturing concept resulting from this Task IV study. With this objective in mind, a typical program plan and master schedule has been developed which meets the objective and which will also be applicable for planning purposes to the GAC and NAR droptank design concepts.

Droptank development is simpler in nature than the parallel development of the orbiter vehicle which paces the NASA schedule for first vertical flight. This program plan, which supports first orbiter vertical flight, thus benefits from a more leisurely pace than otherwise would be required.

The program plan and master schedule as developed and graphically portrayed in Fig. 21-1, Typical External Droptank Phase C/D Program Plan and Master Schedule, is based upon droptank Design Configuration B, defined in Section 7 of this report and recommended as the selected design (and manufacturing) concept best meeting overall design, development, manufacturing, schedule, and cost objectives.

Manufacturing operations planned in this program plan and master schedule are based upon use of the selected "Weld Bond" – Production Concept B as defined in Section 12 of this report.

21.1 TYPICAL PROGRAM MASTER SCHEDULE

The program master schedule consists of two major phases, as shown by the program milestones, the design, development, test, and evaluation phase (DDT&E), and the flight droptank production (procurement) phase.

Section 21
DROPTANK PROGRAM PLAN

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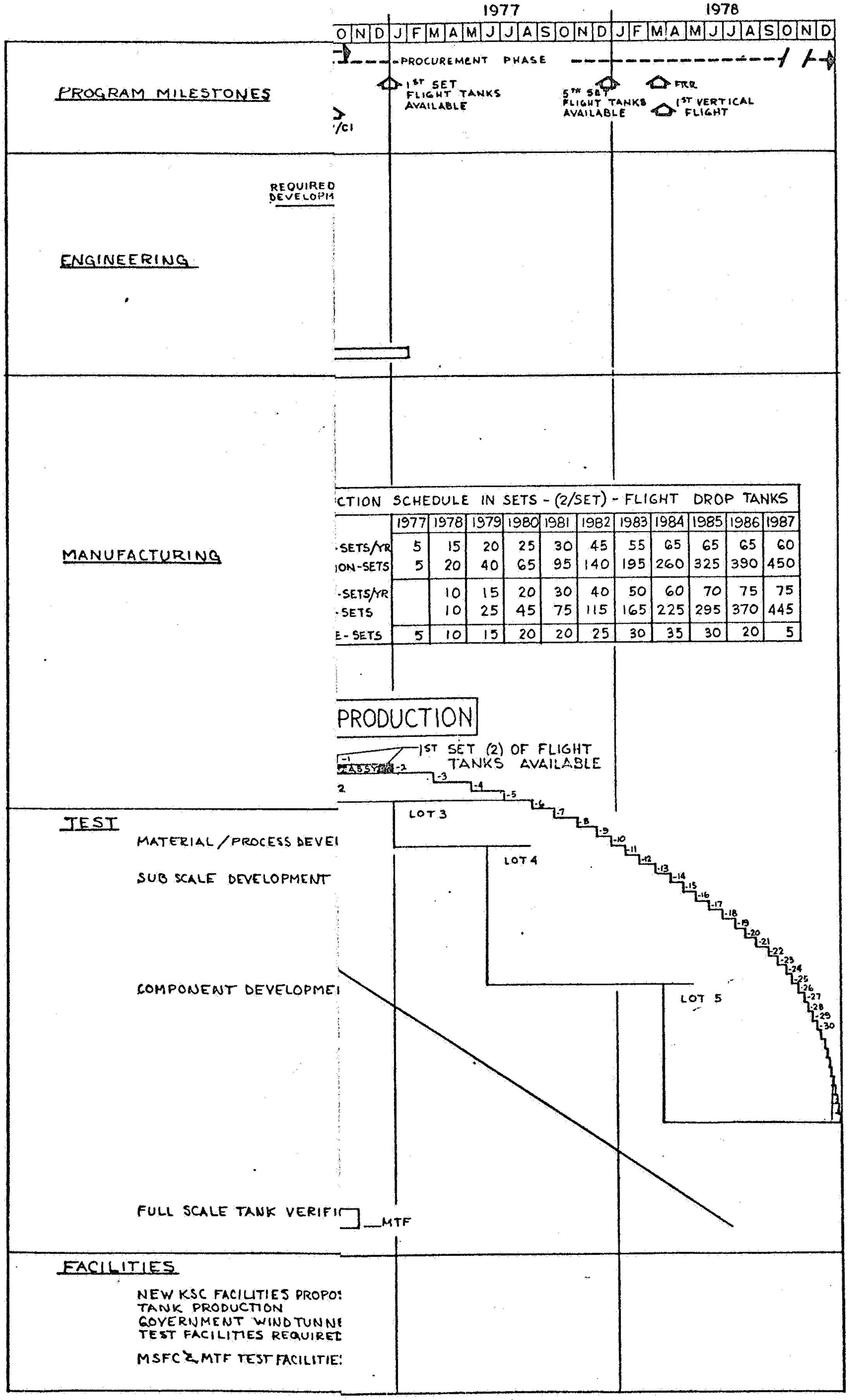
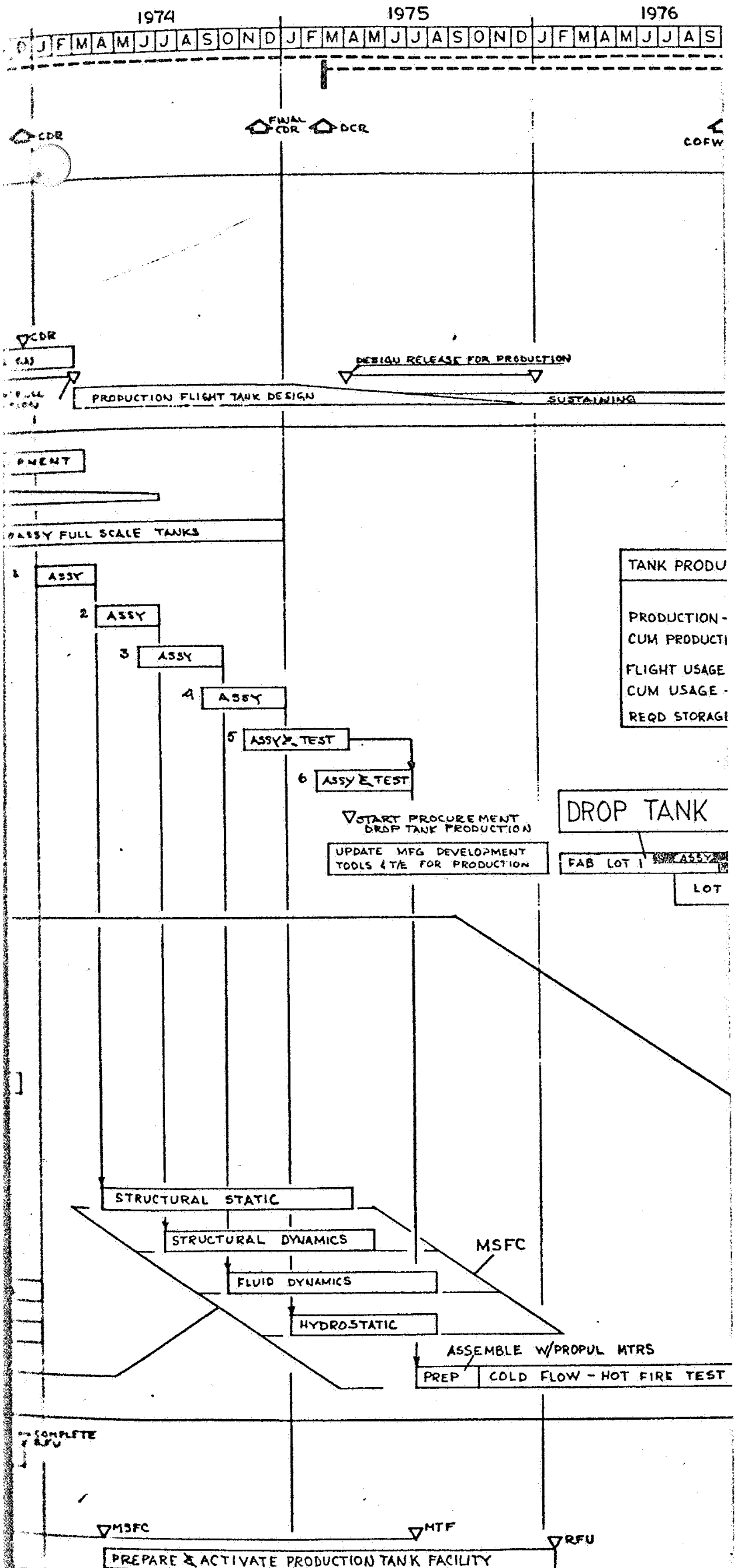


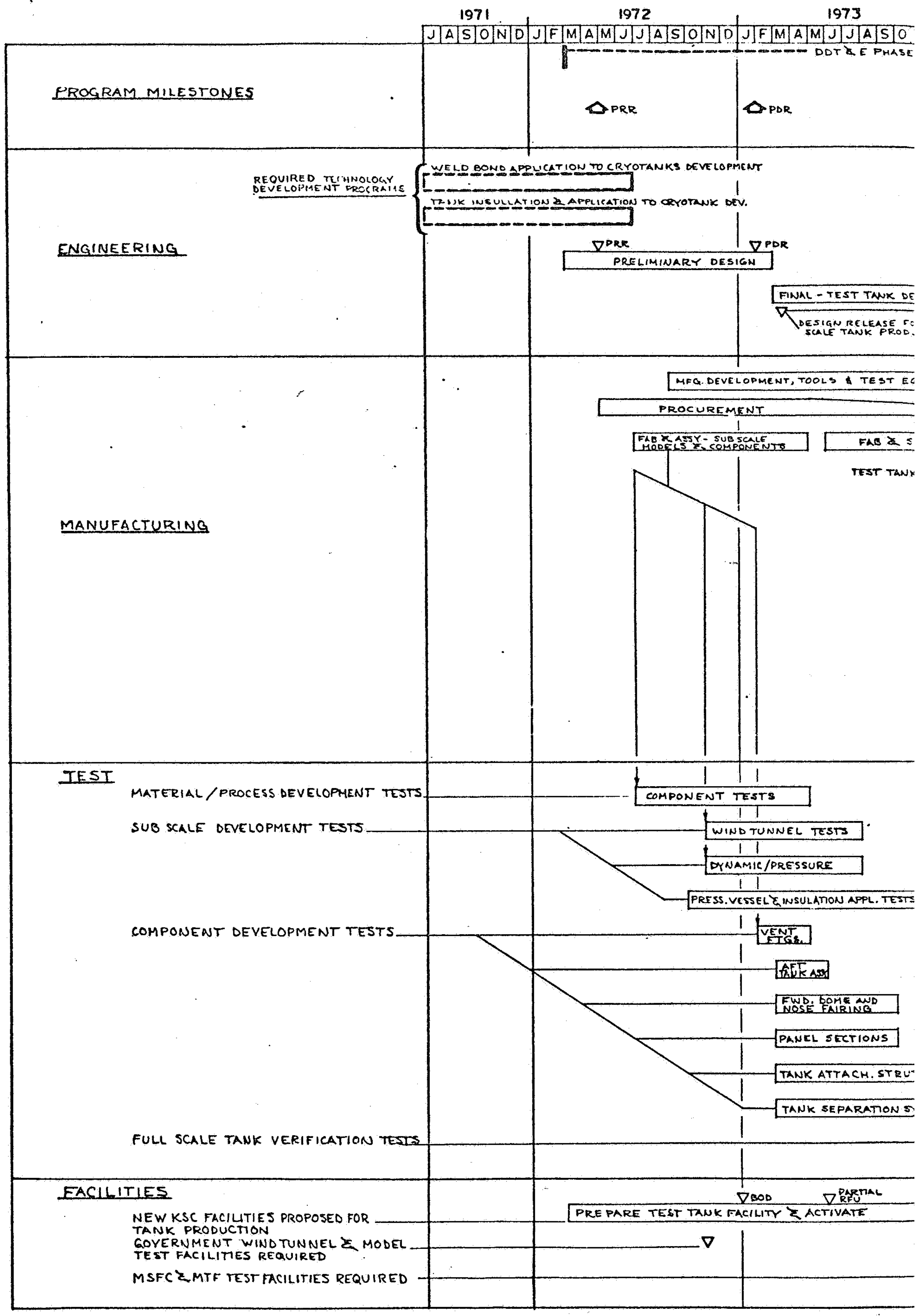
CTION SCHEDULE IN SETS - (2/SET) - FLIGHT DROP TANKS

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
-SETS/YR	5	15	20	25	30	45	55	65	65	65	60
ION-SETS	5	20	40	65	95	140	195	260	325	390	450
-SETS/YR		10	15	20	30	40	50	60	70	75	75
-SETS		10	25	45	75	115	165	225	295	370	445
E-SETS	5	10	15	20	20	25	30	35	30	20	5

TYPICAL EXTERNAL DROP TANK PHASE C/D
PROGRAM PLAN & MASTER SCHEDULE
FIGURE 21-1



1974
1975
1976
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
CDR
FINAL CDR
DCR
CDR
DESIGN RELEASE FOR PRODUCTION
PRODUCTION FLIGHT TANK DESIGN
SUSTAINING
ASSY FULL SCALE TANKS
1 ASSY
2 ASSY
3 ASSY
4 ASSY
5 ASSY & TEST
6 ASSY & TEST
START PROCUREMENT DROP TANK PRODUCTION
UPDATE MFG DEVELOPMENT TOOLS & T/E FOR PRODUCTION
TANK PRODU
PRODUCTION -
CUM PRODUCTI
FLIGHT USAGE
CUM USAGE -
REQD STORAGE
DROP TANK
FAB LOT 1
ASSY
LOT
STRUCTURAL STATIC
STRUCTURAL DYNAMICS
FLUID DYNAMICS
HYDROSTATIC
MSFC
ASSEMBLE W/PROPUL MTRS
PREP
COLD FLOW - HOT FIRE TEST
COMPLETE RFU
MSFC
MTF
RFU
PREPARE & ACTIVATE PRODUCTION TANK FACILITY



1971
1972
1973
J A S O N D J F M A M J J A S O N D J F M A M J J A S O
DDT & E PHASE
PROGRAM MILESTONES
PRR
PDR
ENGINEERING
REQUIRED TECHNOLOGY DEVELOPMENT PROGRAMS
WELD BOND APPLICATION TO CRYOTANKS DEVELOPMENT
TANK INSULATION & APPLICATION TO CRYOTANK DEV.
PRR
PDR
PRELIMINARY DESIGN
FINAL - TEST TANK DE
DESIGN RELEASE FO SCALE TANK PROD.
MANUFACTURING
MFG. DEVELOPMENT, TOOLS & TEST EQ
PROCUREMENT
FAB & ASSY - SUB SCALE MODELS & COMPONENTS
FAB & S
TEST TANK
TEST
MATERIAL/PROCESS DEVELOPMENT TESTS
COMPONENT TESTS
SUB SCALE DEVELOPMENT TESTS
WIND TUNNEL TESTS
DYNAMIC/PRESSURE
PRESS. VESSEL & INSULATION APPL. TESTS
COMPONENT DEVELOPMENT TESTS
VENT FTGS.
AFT TANK ASSY
FWD. DOME AND NOSE FAIRING
PANEL SECTIONS
TANK ATTACH. STRU
TANK SEPARATION S
FULL SCALE TANK VERIFICATION TESTS
FACILITIES
BOD
PARTIAL RFU
NEW KSC FACILITIES PROPOSED FOR TANK PRODUCTION
PREPARE TEST TANK FACILITY & ACTIVATE
GOVERNMENT WINDTUNNEL & MODEL TEST FACILITIES REQUIRED
MSFC & MTF TEST FACILITIES REQUIRED

21.1.1 DDT&E Phase

The DDT&E phase, representing a 48-month time span, should commence early in the 1st quarter of 1972 with program go-ahead and start of preliminary design and a preliminary design review (PDR) early in the 1st quarter of 1973. During this period, fabrication and assembly of subscale test models and test components and subassemblies will be procured and fabricated and component and detail assembly design evaluation testing will be conducted along with wind tunnel testing of aerodynamic models of the droptank configuration and shape. Development of the weld bond manufacturing process for application to cryogenic tank peculiar requirements will be conducted during this period, and design and fabrication of special manufacturing development tools, jigs, fixtures, and test equipment will be undertaken to permit start of fabrication of full-scale test and evaluation tanks by June 1973. Following PDR, final detail design of the tanks will commence in preparation for a critical design review (CDR) in December 1973 and final design release and start of assembly of the first full-scale tank in January 1974. Six (6) full-scale tanks and tank systems will be fabricated for the following evaluation tests:

	Facility
• Structural Static Tests	MSFC
• Structural Dynamic Tests	MSFC
• Fluid Dynamics Tests	MSFC
• Hydrostatic Tests	MSFC
• Cold Flow - Hot Fire Tests	MTF

This typical program plan and schedule assumes the use of new KSC facilities for both full-scale test tank fabrication and for production of flight test tanks. The availability of full-scale tank structural static and dynamic, fluid dynamic, and hydrostatic test facilities at MSFC will be required, as shown on the schedule, as well as full-scale propulsion system and Cold Flow-Hot Fire test facilities at the Mississippi Test Facility (MTF).

21.1.2 Procurement Phase

The Procurement, or flight tank production, Phase under this plan should commence early in 1975, overlapping the DDT&E phase as shown on the schedule to update (harden) weld-bond manufacturing development, special tools, fixtures, holding jigs, etc. and test equipment for full tank production. First planned Orbiter Vertical Flight Test in March 1978 and the planned total flight tests yearly, governs tank production requirements. The learning curve shown on the schedule paces the rapidity of early production deliveries of flight tanks. The droptank production schedule, shown in tabular form on the schedule, provides for delivery of the first set (2) of flight tanks by the end of 1976 and for delivery of five (5) tank sets by the end of 1977 in support of initially planned orbiter vertical flights, and continuing through completion of delivery of 450 tank sets by the end of 1987.

Planned flight usage requirements are shown on the schedule, and the production rate planned considers both these requirements and the production learning curve, and provides for minimum storage of tank sets within these limitations. Maximum storage requirements projected are for 35 tank sets in 1984. Maximum production rate of 65 tank sets per year (130 tank units) is reached in 1984 at the 255th tank unit and maintained through completion of the production program.

21.2 PROGRAM PLANS

Individual plans for accomplishment of the typical program plan for development and production of an external LH_2 droptank system are established and presented in the following passages and include the following:

- Engineering and Development
- Test and Evaluation
- Manufacturing
- Product Assurance
- Facilities and Ground Handling
- Procurement

In some instances the material presented here has been excerpted from the corresponding Technical section of this final report, while in other instances new material is presented. Where excerpting has occurred, specific reference is made to the source material section, where more detailed or definitive information is available.

21.2.1 Engineering and Development Plan

21.2.1.1 Background. The Systems Engineering and Design Engineering organizations participated in the Alternate Concepts Task IV Study, contributing to the total effort in the engineering areas of systems analysis, design analysis, alternate tank concept design and producibility, and program costing and cost sensitivity. The final result of this total study effort has produced the recommendation for a droptank design and production concept based upon Configuration B, Weld-Bonded Droptanks.

21.2.1.2 Engineering and Development Program Description. The overall time sequence and major milestones of the typical Droptank Engineering and Development

Plan are shown in Fig. 21-1, time-phased into the major periods of design development:

- Preliminary Design
- Final Test Tank Design
- Production Flight Tank Design
- Sustaining Design Engineering

Preliminary Design is preceded by two technology development programs required to establish the necessary design criteria and producibility concepts. These required technology developments have a schedule requirement for performance starting in midyear 1971 and completing by midyear 1972 and consist of the following programs:

- Weld-Bond Application to Cryogenic Tank Technology Development
- Cryogenic Tank Insulation and Application to Cryogenic Tank Technology Development

21.2.1.2.1 Preliminary Design Period. The Preliminary Design Period will commence early in 1972 with program go-ahead, followed by a Program Requirements Review (PRR) by the end of April 1972. Preliminary design development will continue throughout 1972 in sufficient depth to permit release of the design necessary for the procurement of test specimens for Material/Process development testing and for the Sub-Scale Development Tests as shown on the Program Master Schedule and as defined in the Test and Evaluation Plan. Preliminary design will culminate in the completion of Part I CEI specifications by the end of December 1972 and in the preparation of preliminary design evaluation drawings in preparation for Preliminary Design Review (PDR) by the end of January 1973.

21.2.1.2.2 Final Test Tank Design Period. Following preliminary approval at PDR, Final Test Tank design development will start in March 1973 to provide initially full-scale test tank structural design release to initiate start of full-scale test tank procurement and fabrication and followed successively by necessary full-scale test tank subsystem detail design release of mechanical systems, electrical systems, propulsion system, instrumentation system, separation and de-orbit system, etc. to permit fabrication and final assembly of full-scale test tanks and test tank systems to support the full-scale tank Evaluation and Verification Test program as shown on the Program Master Schedule and as defined in the Test and Evaluation Plan. Major program milestone events during this design period are the completion of initial Part II CEI Specifications in November 1973 and the initial Critical Design Review (CDR) also in December 1973.

21.2.1.2.3 Production Flight Tank Design Period. Production Flight Tank Design will commence in March 1974, following the last release of full-scale Test Tank design, and will consist of the formalized design drawings, specifications, and documentation required for NASA approval and release for production flight tank fabrication and assembly. Final design changes resulting from the full-scale tank Evaluation and Verification test program will be incorporated into the formal flight tank design to provide the "hardened" design necessary for flight tank production. Major program milestone events of this design period will be the completion of final Part II CEI specifications in November 1974, final Critical Design Review (CDR) in December 1974, and Design Certification Review (DCR) at the end of February 1975. Design release for Flight Tank production will start in April 1975 and continue through the remainder of 1975, completing in December, 1975.

21.2.1.2.4 Sustaining Design Engineering Period. The final period of Sustaining Engineering and Design will commence with the start of design release for flight tank production in April 1975 and continue through production Design Freeze for Class II design changes which will occur with the start of fabrication of the 44th flight tank set. Major program milestones during this design period will be the combined Certificate of Flight Worthiness Review (COFW) and Configuration Inspection (CI) occurring with the completion of acceptance test for Flight Tank No. 1 at the end of August 1976.

21.2.1.3 Engineering and Development Plan. The time sequence of the overall Engineering and Development Plan is shown in the typical Program Master Schedule, Fig. 21-1. In essence, this is a standard systems engineering analysis requirements cycle followed by preliminary design, detail design, test and evaluation and culminating in formalized and approved design documentation for flight test production. The Engineering and Development Plan divides into a Systems Engineering and Integration Plan and a Design Engineering and Development Plan.

21.2.1.3.1 Systems Engineering and Integration Plan. The systems engineering effort during a Phase C/D droptank program effort will be a logical continuation of the systems evolution process.

- Requirements Establishment Period

Occurring early in the Preliminary Design period of the program, this period will consist of those activities involved in defining and establishing the technical boundaries for design. The activity will consist of analysis, study, and documentation with sufficient integration and interface coordination to assure completeness of requirements. The following system requirements and analysis activities will be performed:

(1) System Requirements Establishment

- Conduct Program Requirements Review (PRR)
- Provide System Definition
- Prepare preliminary Part I CEI Specifications
- Provide system and GFP interface requirements definition
- Perform GFP coordination
- Provide test requirements definition

(2) Supporting System Analysis

- Composite System Analyses
- Mission Analysis
- System Trade-Offs
- Performance Trade-Offs

- Development Design Period

The active development design period occurs during the latter half of the Preliminary Design period and during the Final Test Tank Design period and overlaps slightly, but follows carefully the establishment of requirements. During this time frame, detailed development test tank design is in progress, and the full impact of design integration and GFP coordination is applied to the system engineering activity. Monitoring of design progress through daily contacts and scheduled design reviews assures compliance with system and subsystem requirements. Analysis and trade-off studies are performed to substantiate and support design solutions and test requirements will be generated and evaluated. The following specific activities will be performed:

(1) Design Integration

- Finalize Part I CEI Specifications
- Conduct Preliminary Design Review (PDR)
- Perform GFP Coordination
- Integration and Proof of Subsystem Interfaces (including Modeling)
- Prepare preliminary coordination and correlation drawings
- Monitor development testing and perform evaluation of test results
- Provide design evaluation
- Perform liaison engineering in support of design and test evaluation
- Conduct initial Critical Design Review (CDR)

- Production Flight Tank Design Period

During this period, the full-scale test tank design is translated into manufactured hardware and the verification test and evaluation of that hardware occurs. Systems engineering will evaluate test data, monitor specific test programs, and monitor manufacturing and manufacturing test activities. This will also be the period for formalizing development design into production flight tank design and the incorporation of design changes resulting from full-scale tank test and evaluation. Specific System Engineering activities during this period will be:

(1) Test Evaluation and Production Design Integration

- Monitor full-scale verification test programs
- Evaluate test results
- Formalize coordination drawings
- Prepare initial Part II CEI specifications
- Perform production design integration
- Perform liaison engineering in support of design and test evaluation
- Conduct final Critical Design Review (CDR)
- Conduct Design Certification Review (DCR)

- Systems Engineering Sustaining Support Period

Final system checkout of the droptank system with the propulsion system and Cold Flow-Hot Fire test of total system, manufacturing fabrication and assembly of flight tanks, COFW/CI of the first flight tank, and delivery to KSC of the first droptank occurs during this period. Systems Engineering will conduct, monitor, and analyze results of such operations. Specific System Engineering activities of this period will be:

(1) System Engineering Support

- Monitor Droptank system checkout and Cold Flow-Hot Fire Test program at MTF
- Support Flight Tank manufacturing and Manufacturing Test operations
- Support Flight Tank final acceptance testing
- Support COFW/CI of first flight tank
- Support KSC integration and checkout of first flight droptank set with Orbiter vehicle
- Support Flight Readiness Review (FRR) of Orbiter/Droptanks for flight
- Support first Vertical flight of Orbiter Vehicle/Droptanks.

21.2.1.4 <u>Design Engineering and Development Plan</u>. The primary objective and function of the Design Engineering organization will be to develop and document successively, development design and production flight tank design of the external LH_2 droptank system in accordance with system performance requirements. These tasks must also be accomplished within cost and schedule constraints of the contract and Program Master Schedule.

The design engineering organization is divided into functional technical groups, with each functional group responsible for performing the design effort for its cognizant system.

Specific activities of the design engineering functional groups will consist of the following during the design development periods of the program:

- <u>Preliminary Design Period</u>

  (1) Perform preliminary engineering design:

    (a) Prepare preliminary design layouts, schematics, piping diagrams, and specifications for tank structure and subsystems

    (b) Prepare material requests and procurement specifications for raw material and purchased components

    (c) Prepare preliminary general arrangements drawings

    (d) Provide design check and drawing signature approval

    (e) Perform liaison engineering for test specimen fabrication and component sub-scale and subsystem development test

  (2) Provide design analysis in support of design development: Stress, loads and dynamics, aerodynamics, weights, mass properties, thermal hydrodynamics, etc.

  (3) Provide design release for procurement and fabrication of development test component, materials/process, and sub-scale test specimens.

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  (2) Provide design analysis in support of design development: Stress, loads and dynamics, aerodynamics, weights, mass properties, thermal hydrodynamics, etc.

  (3) Provide design release for procurement and fabrication of development test component, materials/process, and sub-scale test specimens.

(4) Provide test specifications, coordination, and evaluation of test results for component, materials/process/and sub-scale test programs

(5) Provide design evaluation drawings, engineering drawing lists (EDL) critical component and long-lead item lists for Preliminary Design Review (PDR)

- Final Test Tank Design Period

(1) Perform final development detail design for full-scale test tanks and tank systems:

(a) Prepare final development detail design, structural design, subsystem schematics, piping diagrams, layouts, wiring lists, assembly drawings, and general arrangements drawings and design specifications

(b) Prepare material requests and procurement specifications for raw material and purchased components

(c) Provide drawing check and signature approval

(d) Provide liaison engineering for full-scale tank fabrication and assembly

(2) Provide design analysis in support of final design development

(3) Provide design release for procurement and fabrication of full-scale test tanks and tank systems

(4) Provide final development design evaluation drawings, engineering drawing lists, critical component and long-lead item lists for initial Critical Design Review (CDR)

- Production Flight Tank Design Period

  (1) Perform formalization design development, design change, and prepare Production Flight Tank design drawing and specifications

  (2) Provide design analysis in support of Production Flight Tank design

  (3) Provide design release for procurement and fabrication of Flight Droptanks

  (4) Provide test specifications, test coordination and evaluation of full-scale tank Evaluation and Verification Test Program

  (5) Provide Production Flight Tank Design Evaluation drawings, final engineering drawing lists (EDL) and Critical Component and Long Lead Item lists for final Critical Design Review (CDR).

  (6) Provide design documentation for Design Certification Review (DCR).

- Sustaining Engineering Period

  (1) Provide sustaining engineering design for incorporation of design changes into Production Flight Tank Design until Class II Change Design Freeze (Flight Tank No. 44)

  (2) Provide design documentation for COFW/CI of Flight Tank No. 1

  (3) Provide liaison engineering to Manufacturing during fabrication and acceptance test of Production Flight Tanks

21.2.2 Test and Evaluation Plan

21.2.2.1 Background

During the course of the study period a considerable effort has been made to isolate and define the areas and types of development testing required; to evaluate materials and processes selected, to evaluate and verify the tank design and manufacturing concept recommended, and to demonstrate and certify the function of the designed and developed droptank system for its use and environment. The results of this effort are pictured graphically on the typical program plan and master schedule, Fig. 22-1 and are defined in detail in the following passages.

21.2.2.2 Test and Evaluation Program Description

An extensive test and evaluation program for tank development and verification will be planned commencing early in the DDT&E Phase. Material/Process investigations and testing will be paralleled by sub-scale model test and evaluation. Component development testing follows to finalize design details, and the planned evaluation program will culminate in a full-scale tank test and verification program to demonstrate the soundness of the droptank design.

21.2.2.3 Material/Processes and Sub-Scale Development Testing

Early in the Preliminary Design period sub-scale models and tanks will be fabricated for aerodynamic, dynamic and pressure testing and evaluation. A small scale pressure vessel will be fabricated by the weld bond technique for evaluation and insulation application techniques and effectivity will be tested and evaluated. Material and process investigations will be conducted and extensive evaluations of fracture and subcritical flaw growth characteristics of parent metals, weld-bond joints and repaired weld-bond joints will be made. Development tests planned are detailed in Table 21-1.

21.2.2.4 Component and Sub-Assembly Development Test and Evaluation

During the preliminary design period extensive development testing of components, detail assemblies, and tank segments, and sub-systems will be made to evaluate and finalize the droptank design. Hardware specimens will be fabricated specifically for test and evaluation during this period as shown on the master schedule. Development tests planned are detailed in Table 21-1.

21.2.2.5 Full Scale Tank Test and Verification

Fabrication of full-scale tanks for structural testing will be started during the Final Detail Design period as shown on the Master Schedule. Following Critical Design Review (CDR) and release of Final Design, assembly of the planned (6) full-scale tank and tank systems will be commenced. Full scale structural (static), dynamic, fluid dynamic and hydrostatic testing at the Marshall Space Flight Center will be followed by a full-scale functional check-out of droptank cryogenic systems with a "cold-flow" test at the Mississippi Test Facilities. Finally, a droptank set will be mated with main propulsion system (or comparable Orbiter vehicle); tank filling and "pre-launch" checkout performed; and run through total commit sequence through engine ignition will be conducted to demonstrate full system checkout, facility verification and operational procedure correctness. Full definition and details of this series of planned testing are listed in Table 21-1.

Test Phase	General Procedures
A. Material/Processes.	
Extensive evaluation of fra subcritical flaw growth cha Specimens to include sample metals, weldments and repai	Test procedures, material samples, etc., shall be in general accord with established ASTM standards and recent NASA and AF reports concerning testing of materials for cryogenic pressure vessels/propellant tanks.
B. Sub-Scale Development Scale models of LH_2 tanks (approx. scaling, selected s factor will be dependent upc avilable tooling and manufac capabilities).	General practices for wind tunnel testing is outlined in the NASA ASA "SP" documentation series. Scale model tanks will be tested under various static, pressure and temperature combinations to evaluate Design & Fabrication Concept. Pressure tests at ambient and cryogenic (LH_2) temperatures will include thermal, proof cyclic and burst. Pre and post test inspection methods and criteria will be emphasized. Data (some concurrent) from material fracture mechanics analyses will be incorporated in model tests/specimens. TPS system will be evaluated.
C. Component Development	
1. Vent Fittings	Subject full scale fitting and associated stiffeners, doublers and interface rings to limit, ultimate and failure loads.
2. Aft Assembly (Cone and gore panels, 14 ft dia by 10 ft higl	Proof and burst tests with water require normal safety precautions. Cryo tests will require remote site and other special safety procedures. Specimens will be instrumented with strain gages and deflectometers.

Table 21-1

SPACE SHUTTLE

...ER EXTERNAL LH_2 TANKS

DDT/E PHASE

Description

...vestigations will include a laboratory test ... obtain data on plane-strain fracture tough-...shold stress-intensity and subcritical flaw ... parent metals as well as weldments. These ...tics will be evaluated at critical environ-...itions (tank operating temperature and ... temperature). Effects of material and manu-...processes on fracture characteristics shall ...ed.

...l tests at government facilities to verify ... aerodynamic coefficients and pressures; ...sts to obtain fuel sloshing loads and to ...ffectiveness of slosh-suppression devices; ... pressure loading of tank models under ...itions from ground handling through ... and impact.

...nt and type of pre-proof inspection required ... proof test as the final tank inspection

...ressure Vessel Tests for Weld ...ique qualification and TPS ...ification will be conducted.

...ctural integrity of vent fittings for the ...ression design loads.

...atic proof pressure at ambient temperature ...ter.

...atic proof at cryo temperature with LH_2.

...atic burst at ambient temperature.

Test Phase	Test Type	
A. Material/Processes. Extensive evaluation of fracture and subcritical flaw growth characteristics. Specimens to include samples of parent metals, weldments and repaired weldments.	Material Development	Materia program ness, th growth f characte mental c proof te facturin be evalu
B. Sub-Scale Development Scale models of LH_2 tanks (approx. scaling, selected scale factor will be dependent upon avilable tooling and manufacturing capabilities).	Model	Wind tun analytic dynamic validate static a mission separati Assess a to valid method. Subscale Bond tec system v
C. Component Development		
1. Vent Fittings	Static	Verify s axial co
2. Aft Assembly (Cone and gore panels, 14 ft dia by 10 ft high)	Pressure	a. Hydr with b. Hydr c. Hydr

Test Phase	General Procedures
C. Component Development (conti	
3. Forward Dome and Nose Fa (about 14 ft dia by 10 f	Proof and burst tests with water require normal safety precautions. Cryo tests will require remote site and other special safety procedures. Specimens will be instrumented with strain gages and deflectometers.
4. Panel Sections	Test aft gore panels and cylindrical bond panels. Evaluate panel configurations in reverberant and incident type acoustic environments.
5. Tank Attachment Struts	Apply axial loads up to limit (145,000 lbs) and to failure. Also apply corresponding lateral axis static loads. Ascent flight loads may be applied under heated conditions.
6. Tank Separation System	Multi-phase project encompassing pyrotechnic bolts/pin pullers/other concepts up to mass simulated tanks.
7. Miscellaneous component RDT/E Tests	Includes structural, thermal, dynamic pressure and operational type tests. Specimens will range from breadboard devices up to flight configuration components.
D. Full Scale Tanks	Subject test tank to limit, ultimate and failure loads. Ambient temperature tests will require only normal safety precautions. Special load and reaction fixtures must be designed and fabricated. Approximately 300 digital data channels will be used.

Table 21-1 (Cont'd)

SPACE SHUTTLE

...R EXTERNAL LH_2 TANKS

DDT/E PHASE

Description

...tatic proof pressure at ambient temperature
...ater.
...tatic proof at cryo temperature with LH_2.
...tatic burst at ambient temperature.

... load - evaluate effect the joint details have
...kling strength of tank cylindrical shell panels.
and lateral loads.
...c load - confirm structural integrity of panel
...ns in an acoustic field with levels up to
...

... Load - confirm structural integrity of forward
...r aft attachment struts under static design
(limit, ultimate, failure).

...ility of separation device(s) to perform ade-
...i.e., activate pyro units, separate disposable
etc. Determine initial separation character-
...r simulated tanks.

...es component elements such as liquid level
pressure switches, insulators, temperature
...rs, propellant feed units, vent and pressuri-
...stems, support brackets, LH_2 tank bulkhead
etc.

...tural Test Tank - static test conditions will
...de considerations of max Q, ground wind,
...ial, rebound, first stage separation, and
...ion loads. Axial, shear and bending moment
... will be applied separately and/or simul-
...usly under ambient temperature conditions.
...us hydrostatic tank pressures will be employed.
...ble need for static test at cryo temperatures
be evaluated.

Test Phase	Test Type	
C. Component Development (continued)		
3. Forward Dome and Nose Fairing (about 14 ft dia by 10 ft high)	Pressure	a. Hydr with b. Hydr c. Hydr
4. Panel Sections	Structural	a. Stat on b Axia b. Dyna sect 175
5. Tank Attachment Struts	Structural	a. Stat and/ load
6. Tank Separation System	Functional	Verify a quately, elements istics i
7. Miscellaneous component RDT/E Tests	Development/ Qualification	Encompas sensors, transduc zation s fittings
D. Full Scale Tanks	Development/ Qualification	a. Str inc ine ign loa tan Var Pos wil

Test Phase	General Procedures
D. Full Scale Tanks (continued)	Several small (less than 250 lb force) shakers will provide excitation loads. Test setup will require an enclosed area to minimize air currents, etc. About 100 analog data channels will be used. The special slosh test facility at MSFC should be used. Tank mounting requires unique fixtures. Excitation loads will be provided by servo-controlled hydraulic cylinders. Test instrumentation will include accelerometers, strain gages, deflectometers, pressure transducers and high speed cameras. The hydrostatic test tank plus test tanks from the dynamic and fluid test programs will be utilized. Test criteria may include proof pressure at ambient and cryogenic temperatures; helium leak checks; hydro-pneumatic proof test at ambient temperature; ultimate pressure at cryogenic operating temperatures; burst tests at ambient temperature. Pressurization media/techniques to be investigated will include (not limited to) de-ionized water; simulated propellants; LH_2 to cool tank to operating temperatures; need for a vacuum chamber to assist temperature conditioning of tank; use of acoustic emission technique as a proof test aid.

Table 21-1 (Cont'd)

SPACE SHUTTLE

...ER EXTERNAL LH_2 TANKS

DDT/E PHASE

Description

. Test Tank - modal vibration test of a complete
sembly. Excitation conditions will simulate
ce lateral and longitudinal modes, cantilever
. mode and free-free torsional mode. Several
ll conditions will be simulated to determine
apes, frequencies and damping factors.

ynamics Test Tank - slosh test to verify
e distributions on anti-slosh baffles. Subject
horizontal vibration with several low fre-
sinusoidal inputs and excitation amplitudes.
tank fill conditions (simulated propellent)
ig will be employed.

atic Test Tank - a series of internal pressure
ill be run to assess the structural integrity
l tank design and establish design allowables.
tion, these tests will be directed at develop-
verifying proof test procedures and inspection
a for production tanks. Other test objectives
determination/verification of tank failure
nd assurance of "safe-life" design concepts.

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Test Phase	Test Type	
D. Full Scale Tanks (continued)	Development/ Qualification	b. Dynam tank free- later tank mode
		c. Fluid pressu tank quency Severa at 0
		d. Hydros tests of fir In add ing an criter includ modes

Test Phase	General Procedures
D. Full Scale Tanks (conti	Conduct of RDT/E activity at MTF must be coordinated and run in conjunction with GAC and NASA. As the program manager, GAC will probabl direct all contractor effort an LMSC will provide technical support similar to launch operations.

Table 21-1 (Cont'd)

SPACE SHUTTLE

RBITER EXTERNAL LH_2 TANKS

DDT/E PHASE

Description

Flow - Will probably be conducted at the ssissippi Test Facility. Will serve as a ctional check-out of drop tank cryogenic systems final check-out of test facility. Assemble k halves, fill propellant tanks, flow cryogens parately and check-out pumping, valves, lines, ernal pressurization system, etc. Check-out ility and "flight" instrumentation systems.

Firing - A drop tank set will be mated with a parable Orbiter test vehicle or main propulsion stem; tank filling and complete pre-launch check- sequence will be conducted. Run through total nt sequence through engine ignition. Test will rve as a system check-out, facility verification operational procedurs demonstration.

Test Phase	Test Type	
D. Full Scale Tanks (continued)	Development/ Qualification	e. [illegible]
		f. [illegible]

21.2.3 MANUFACTURING PLAN

21.2.3.1 Background

The LMSC Manufacturing organization participated with Design Engineering and Producibility Engineering throughout the study phase to arrive at design and manufacturing concepts for a producible, low-cost tank, utilizing current technology and state-of-the-art methodology, machining and equipment. A production analysis and cost was performed on three selected design and fabrication concepts. Groundrules applying to manufacturing were established as follows:

- Production of 450 sets of tanks
- Fabrication assembly to be performed in a government furnished facility located at the Kennedy Space Flight Center
- Engineering design freeze for Class II changes to be established at Tank Set No. 44
- Manufacturing's effort to consist of fabrication, assembly and test of fully instrumented tanks with thermal insulation applied

For purposes of this typical program plan, Production Concept "B" defined fully in Section 12 of this report, has been selected as most advantageous and is presented here.

21.2.3.2 Configuration and Manufacturing Description

Concept B is a weld-bonded (spotweld through adhesive bond) design and production concept using 2219-T82 aluminum alloy material over a doubler framework structure. Assembly breakdown and sequence is shown in Fig. 14-5 and fabrication weldment assembly, final assembly and test operational steps are fully defined in Section 12 of this report.

21.2.3.3 Tooling Philosophy

During the DDT&E phase limited durable tools consistent with design and program requirements will be provided. Major tools will be designed and constructed so that they will support the development phase at minimum cost. Through modifications and additions these tools will also be used to support the production phase. Tooling requirements have been planned on the basis of high usage of automation through numerical control, peak rate considerations, optimum utilization, low maintainability and tool utilization as an in-process inspection media. Under the Concept B — weld-bonded tank, longitudinal and circumferential weld are made with the same piece of equipment. Multiple, removable spotwelding heads or rolls have been considered and are under investigation. Staging will not be required for this approach since all welding is accomplished at a low level.

21.2.3.4 Manufacturing Testing

The Production Test program will encompass "In-Process Tests" and "Manufacturing Acceptance Tests," and are fully defined in Section 12.6 of this report, along with test level definition and a description of the test to be performed. Line flow testing philosophy shall be applied during manufacturing operations. Component subassembly and final assembly testing shall be accomplished where applicable, to assure integrity and system operation of the deliverable tank assembly.

21.2.3.5 Manufacturing Test Equipment

The manufacturing approach to production testing requires that the total relationship between test equipment and design requirements be thoroughly examined. Four basic interfaces are considered:

1. Design limits
2. Test Equipment limits
3. Test Interface (Test equipment/Item under test)
4. Test Equipment Output (Test Hardware/Program)

Test equipment requirements for Component, Subassembly and Final Assembly acceptance testing are fully defined in Section 12.6.3 of this report.

21.2.3.6 Packaging and Handling

In this typical program plan, a total of six test tanks will be prepared for shipment from the Kennedy Space Flight Center (KSC). Four tanks will be shipped to the Marshall Space Flight Center (MSFC) and two to the Mississippi Test Facility (MTF).

Each tank will be intact with a strongback attached and the tank in tension and pressurized. The tank will have a protective cover to prevent damage and to control tank environment during transportation. An auxiliary pressurization system will be provided. Transportation considered is single shipment by barge-transit times by barge to MSFC and MTF are seven and twelve days, respectively.

21.2.4 PRODUCT ASSURANCE PLAN

21.2.4.1 Background

The LMSC Product Assurance organization has the responsibility of supporting the design, manufacturing, and procurement functions in order to provide an independent assurance of reliability, maintainability and quality.

During the Study Phase, Product Assurance efforts were directed by two factors, "High Quality and Low Costs." To achieve these objectives, a continuing quality assurance analysis of the droptank design concepts was made to determine the quality levels required. Close coordination with the Manufacturing organization provided the proposed technique for manufacture, assembly and testing of the tanks.

21.2.4.2 Quality Program Description

A Quality Program which supports the selected Design and Manufacturing Concept B – Weld Bonded Droptanks of this typical program plan will have the following objectives:

- Quality support should start at the beginning of the DDT&E program. Through design reviews and design coordination, the Quality Engineer will influence the tank design to reflect quality considerations which will contribute to "High Quality and Low Cost."
- Tool designs at all levels of tank details, subassemblies and assemblies will be studied to make maximum utilization of the tool as the means for inspecting and accepting tank hardware.
- Manufacturing sequences for the candidate design has been studied and the performance of quality verifications will be controlled with "Integrated Planning" which combines the Shop Work Authorizing Document and the Inspection Instructions into a single document.

- Manufacturing Process Control will be vigorously enforced — the nature of the processes for the candidate tank designs, such as, spotwelding, weld-bonding, polyurethane foam spraying, ablator application, cleaning, etc., are such that much effort can be devoted to locating defects which will not exist within predetermined acceptable limits due to Process Control.
- Development programs will be conducted by Product Assurance to develop the manufacturing process criteria which will meet all specification requirements. These tests will be conducted during the development phase in order to meet the first production tank assemblies.
- Acceptance Testing will be conducted jointly with the Manufacturing test of the tank assemblies. Quality Engineering will review and approve the Acceptance Test Procedures, certify the test station, certify the test personnel, record all discrepancies and take appropriate corrective action.
- Material Review/Corrective Action systems will be provided as necessary to ensure the correct disposition decision is made on discrepant material — High Quality — Low Cost.
- Supplier/Subcontractor Quality will be controlled to minimize discrepant material from being shipped. Additional controls such as cleanliness, packaging, identification/configuration control are typical of areas where the initial cost at the supplier's facility is the final cost and that recurring effort will not be required at the tank assembly facility.

21.2.4.3 Controlled Production Tooling

Controlled Production Tooling referred to as Inspection Media Tooling are those tools so designed as to act as their own criteria for Inspection. Tooling in this category are designed substantially for greater accuracy and long life. Product Assurance-Quality Engineering performs the design review and quality inputs to the Tool Design-Engineering organizations.

All tooling for the weld/bond configuration will be designed for maximum utilization of the inspection media concept. Present experience with the Centaur Standard Shroud has demonstrated that the tooling need not be excessive for application and control of adhesive and placing of spotwelds.

21.2.4.4 Weld/Inspection Concept – Concept B – Weld/Bonded Tank Assembly – 2219-T82 Aluminum

Weld/bonding is spotwelding through an adhesive bond which is a mature manufacturing process currently in use at Lockheed Missiles & Space Company on the Centaur Standard Shroud. This concept has the lowest estimated overall quality costs and through the development of acceptable inspection capabilities, has the greatest potential for cost effectiveness.

The combining of the best features of spotwelding and adhesive bonding provides low cost spotwelding and eliminates the need for costly tooling and assembly necessary for adhesive bonding – the spotwelds act as the holding fixture. Additionally, the high joint strength of the adhesive bonding overcomes the low fatigue strength of spotwelds. Some off-the-shelf equipment exists that can provide the necessary inspection capability.

A quality development program will be conducted to confirm the ability of the inspection techniques used to ensure the fulfillment of specification requirements. Repair procedures will be required when discrepant spotwelds or adhesive bonding are detected.

21.2.4.5 Acceptance Testing

During the droptank manufacturing sequence, a line-flow testing philosophy shall be used. Component, subassembly, and final assembly testing will be performed where applicable and as a minimum Product Assurance will control all acceptance testing in the following manner.

- Review and approval of Acceptance Test Procedures for Lockheed and supplier performed acceptance testing, to ensure test level conforms to Design Specification requirements.
- Certify Lockheed and supplier test stations and test personnel to ascertain readiness for test. Review and approve (if applicable) Equipment Test Procedures.
- Witness all acceptance tests.
- Record all discrepancies found during test and direct corrective action decisions to rectify the known discrepancy and to preclude its recurrence.
- Assist in developing test data requirements to be taken during test. This data will be essential to producing objective evidence that sample testing of production tanks is in order after a certain confidence level has been achieved.
- Upon the successful completion of acceptance testing, clearly indicate on the hardware as well as the supporting documentation the quality acceptance.

21.2.4.5.1 Safety Considerations. During all phases of acceptance testing, safety of test personnel and the inability to damage the hardware will be major quality objectives. Each test procedure and test station will be evaluated for its inherent safety characteristics.

21.2.4.5.2 Components and Subassembly Level Testing. Analysis of the components and subassemblies which require tests indicate no major problems for Product Assurance during hardware acceptance. One area of concern is to control cleanliness all through the component and subassembly buildup to minimize the difficulty of the final tank cleaning.

21.2.4.5.3 <u>Final Assembly Level Testing</u>

- Proof Pressure and Leak Test will determine the integrity of the tank as a pressure vessel and the validity of the piping joint interfaces at tank flanges. Further development work will be required to utilize Acoustic Emissions as the means to detect incipient failures in pressure vessels by stress-wave emissions.
- Tank Cleaning (Internal) will be controlled by combining on-line electronic particle-counters with samples to be lab-tested. The laboratory will directly support the cleaning operation. Here again, some development work is necessary to increase the capability of the electronic counters. It is anticipated that a visual black-light examination might also be necessary to meet contamination specifications.
- Tank Handling and Storage

  Recognizing the vulnerability of thin-walled tanks, Product Assurance is concerned with improper handling which might damage the tank assembly, degradation of the storage pressure which might cause collapse of the tank assembly and the ability to store the tank assemblies without invalidating their previous acceptance. Determination of any time/life cycle materials will be made and adequate storage surveillance procedures should be prepared and will include safety requirements as well.

21.2.4.6 TPS Inspection Concepts

To minimize heat leakage into the LH_2 during ground and boost operations, Product Assurance has determined that two techniques appear to be the most practical and least expensive to assure the quality of the proposed layered ablator and cellular foam insulation. The one technique is radio microwave scanning, the other is process control.

- Cryogenic Insulation

  The low density (2.0 lb/ft^3) of the foam mandates that development tests be conducted by Product Assurance to develop the acceptance techniques either through rigid process control, nondestructive inspection techniques, or a combination of both.

- Ablator Materials

  Radio microwave scanning of the ablator material will give rapid realtime verification of the density, thickness, and bonding characteristics. Disbonds and voids (1/4 sq in. or larger) can be readily detected and recorded on tape to expedite rapid repair as required.

  Quality controls will also be invoked on the suppliers of the ablative materials, such that his laboratory reports, test data on lot certifications can minimize in-house acceptance of the material.

21.2.4.7 Other Quality Considerations

Repair or rework requirements will establish the time phasing for the Acceptance inspections. For example, it may be possible to reduce inspection time by scanning the tank assembly with microwaves only when it is complete. Such parameters as adhesive disbonds, voids and coating thickness can be verified, however, repairs or rework at this phase may be unacceptable. Studies of these type of tradeoffs are critical to developing the quality system which will ensure "High Quality and Low Cost."

Problems with aluminum corrosion have been reviewed and Product Assurance will assist in the development of the process to ensure that, correct primers are used, surface conditions will provide continuous coverage, proper curing capability and controlled ambient conditions. The proposed manufacturing plan to build a complete tank before spraying on the primers will enhance the chances of coating the entire surface with a heat cured primer such as M-602.

21.2.5 Facilities, Ground Handling, and Logistics Storage

21.2.5.1 Background. The existing KSC MILA area is assumed for purposes of this program plan to be the baseline site for new flight droptank manufacturing facilities becuase of the adjacency of manufacturing operations to operational usage and the resulting logistics support advantages thereof. The construction of new buildings adjacent to the VAB high-bay cells is assumed to reduce the transfer distances required for logistics ground handling for both the orbiter vehicle and the droptanks as presented in EM L2-05-04-M1-1, dated 8 December 1970, which is presented in Section 2.1.5, Operations Analysis, Pages 2.1.5-1 through 2.1.5.-66 of LMSC-A-981489, ACD-072, dated 15 December 1970, Fifth ACS Letter Progress and Status Report.

21.2.5.2 Facilities Plan. This plan assumes construction of a new Droptank Manufacturing Facility at KSC for flight tank fabrication, testing, cleaning and storage; a new Maintenance Annex to the existing VAB for orbiter vehicle checkout, refurbishment, and repair; and two cells of the existing VAB modified for droptank-to-vehicle mate and checkout.

The droptank manufacturing facility will be required to provide the space and equipment needed to fabricate, assemble, clean, test, insulate, and store the droptanks. It will be located across from the new VAB maintenance annex for ease of tank transfer to the VAB high-bay cells.

Use of new or modified existing facilities at KSC are also assumed for the fabrication and assembly of component, subscale and full-scale droptanks test hardware for the droptanks development and verification test programs as shown on the program master schedule, Fig. 21-1. In addition, government-furnished wind tunnel, dynamic, and pressure test facilities will be required as shown on the program master schedule to support the subscale tank testing program. Use of Marshall Space Flight Center (MSFC) static structural, vibration, fluid dynamic and hydrostatic test facilities and Mississippi Test

Facility (MTF) Cold Flow-Hot Fire test facilities will be required as shown on the program schedule for support of the full-scale droptank verification test program.

21.2.5.3 Tank Ground Handling Plan. The droptanks will be received from the manufacturing final assembly and positioned on a transport dolly, pressurized, and held in tension in the manufacturing strongback structure. The tank will transported to logistics storage in the vertical attitude. The tanks are tilted to the vertical on the transport dolly and placed on a rail or truck system for sequential storage. They will be stored under tension in their manufacturing support structures, pressurized to 3-5 psi, with a suitable monitoring and alarm system. The manufacturing strongbacks will then be recycled for use.

When required for use, the tanks will be removed from storage in the same sequence as they entered. A tank when removed from storage will be placed on a transport dolly and tilted to the horizontal attitude. The transport dolly design will incorporate impact recording and ancillary pressurization capabilities.

The transport dolly will be utilized to transfer the tank to the mating area unless the crane rail can be utilized to perform the operation.

Mating of the tanks to the orbiter will be accomplished by use of a ground handling fixture which will be designed to perform the task both horizontally or vertically. Transfer of the tank to the ground handling fixture will be made possible by the use of different attach points in each case. The manufacturing fixture will be secured to the flight fittings on the tank caps, while the gound handling fixture attaches to special lugs provided for it. Once secured in the ground handling fixture, the tank will be hoisted in either horizontal or vertical position, and with the flight attach interfaces freed, the tank is then secured to the orbiter vehicle. The ground handling fixture will be designed to perform its lifting and mating function as well as to provide the required longitudinal tension to protect the tank should there be a loss of pressure during handling operations.

Tilting capability will not be built into handling equipment since it already exists in the manufacturing dolly. However, to permit hoisting in either attitude, two different length cable slings will be required and equipped with a built-in capability to compensate for center-of-gravity shifts and permit level hoisting. Additionally, a vertical micropositioning device will be required between the sling and the overhead hoist to permit precise vertical adjustments during mating.

The following equipment will be required for tank ground handling:

- Transport dolly - equipment with "G" impact recorders and ancillary pressure supply
- Hoisting and mating fixture
- Vertical hoisting sling
- Horizontal hoisting sling
- Micropositioning device

21.2.5.4 <u>Logistics Storage Plan.</u> This plan is applicable to droptanks, either accepted by NASA and waiting for delivery to the Orbiter Vehicle/Droptank mating operation or upon completion of manufacture and acceptance test and waiting for delivery to the Orbiter Vehicle/Droptank mating operation.

Logistics and Material Operations will receive and assume custody of the Droptanks and kits of struts and pyro devices upon completion and final acceptance. The storage site selected will be the low bay of the KSC VAB building, as shown in Section 12 of this report. Scheduling of droptanks into and out of storage will be in accordance with the Space Shuttle Master Schedule.

Space Shuttle droptanks will be delivered to the storage building pressurized and prepared for storage in accordance with a storage specification.

Related documentation received with the droptanks will include the Droptank Storage Log Book (DTSLB) which, verified by Product Assurance, will reflect the actual physical condition of the droptank and other data pertinent to the storage activity.

Present information indicates that storage building floor space limitations, based on the vehicle assembly building lower bay area, preclude storage of more than 42 tanks in a horizontal position. Since the present production schedule indicates a need for storage of a maximum of 70 tanks in the same time period, scheduling of actual production to alleviate this condition will be required.

Due to door height limitations, droptanks will enter and exit the storage building in a horizontal position.

Refurbishments, minor modifications, and repairs can be accomplished within the storage area by manufacturing personnel. Logistics management pertaining to limited calendar-life items and associated logistics management will require additional study.

21.2.6 PROCUREMENT PLAN

21.2.6.1 Background

The LMSC Procurement organization participated with the Design Engineering and Manufacturing organizations throughout the study period securing and providing realistic vendor and supplier costs in support of the detailed cost analysis conducted for the three selected design and fabrication concepts. The cost and supplier data gained will be utilized to great advantage during a Phase C/D contractual effort for droptank development and production.

21.2.6.2 Procurement Program Description

Procurement of material for a droptank development and production program will be handled in accordance with existing Lockheed procedures by personnel who have gained their experience on prior NASA programs. The procedures for placing orders and subcontracts and controlling them are fully developed, as are the working relationship with the project organizations that are responsible for establishing the requirements for droptank materials, services and hardware.

The LMSC organizations responsible for design, manufacture, test, inspection, documentation, and logistics support will initiate the requirements for materials, services and hardware. Procurement will analyze the requirements, purchase the items, administer their operations, control material cost, receive and deliver purchased items to the user, and provide advice and assistance on sources, delivery spans, and costs. Procurement will review each droptank Engineering Data release to make sure that the requirement is properly budgeted, and that the requirement is consistant with the program schedule. Procurement personnel will perform liaison between design engineers and potential suppliers to obtain specifications and technical data on materials.

The status of all procurements will be maintained for program and management visibility and control. Procurement evaluates the past performance of potential supplier prior to placing orders. Delivery and cost performance are both considered in this evaluation.

Supplier products will be delivered to LMSC or to test facilities by the most economical means of transport. The LMSC Traffic organization will assist in coordinating shipments, selecting carriers, and expediting emergency needs.

21.2.6.3 Long-Lead Items List

A long-lead items list will be established early in the droptank development period and will be updated and maintained during the flight tank production period. The procurement spans for long-lead items will be monitored and coordinated with design to assure that procurement specifications and requirements are available so that the hardware can be obtained as required by the program schedule.

21.2.6.4 Make or Buy

Lockheed has well-established Make or Buy policies and procedures that are in agreement with current ASPR, NPD, and Small Business Administration policies and these policies and procedures will be followed on the droptank program. A preliminary Make or Buy list will be established early in the droptank development program and will be maintained and modifed as the detail design is worked out, as supplier capabilities change, and as LMSC's in-house capability changes.

21.2.6.5 Subcontract Administration and Control

Lockheed procedures require formal RFQ action on all procurements except for inexpensive, regularly stocked items. Procurement coordinates the RFQ with the requesting organization and with Product Assurance. Competitive bids will be solicited whenever possible.

Procurement will issue formal subcontracts or purchase orders for all droptank purchases. Subcontract administrators continuously monitor and review the subcontracts for which they are assigned responsibility, giving particular attention to cost and schedule performance. In addition, on large and complex procurements, teams representing the Program Office, Procurement, Engineering and Product Assurance regularly visit the plants of major suppliers to review progress, problems and financial status. When the interface with the subcontractor's hardware is complex, or when the subcontractor has problems, a Lockheed representative may be assigned to a supplier's plant to assure satisfactory information flow and prompt performance.

Lockheed's relations with its suppliers are regulated by a well-established set of policies and procedures. These policies and procedures were approved by the cognizant DOD agency in 1965 and the approval has been renewed annually.

All communication between suppliers and LMSC will be processed through Procurement to assure cost control and compliance with subcontract requirements. Technical definition and program direction for the subcontractor will be coordinated and transmitted by the Procurement organization.

Section 22
PARAMETRIC PROGRAM COSTING

22.1 UPDATING OF CERs

In the course of previous Lockheed work on Space Shuttle programs, Lockheed has developed Cost Estimating Relationships (CERs) for predicting the costs of expendable droptanks. These were directed mainly to stage-and-one-half configurations in which the droptanks had no de-orbit system, were designed to carry both oxygen and hydrogen, and were in the range of 100,000 to 120,000 lb/set. The CERs correlated very well with various detailed estimates (See EM L2-02-01-M1-2 in Appendix) for fusion-welded aluminum tanks and are presently being used in estimating stage-and-one-half system costs. The detailed cost estimates developed under the current external-tank orbiter task provided the opportunity to check and update the existing CERs to make them applicable to smaller hydrogen-only tanks.

The current CER for theoretical first-unit cost for the larger tanks is

$$TFU = 5.95 \times 10^3 \times (W)^{.607} \times F_c$$

where W is the dry weight of one tank and F_c is a complexity factor for type of construction and material. For the larger stage-and-one-half droptanks, the complexity factor for basic structure is 1.0 (for skin/stringer aluminum construction). Insulation, plumbing, and attachments are assumed to have the same complexity factor as the basic structure to give an overall F_c of 1.0.

22.2 CONCEPT A TANKS

The total dry-weight distribution of the external tanks of Concept A including the 10-percent contingency is:

Structure	6,954 lb
Insulation	7,492 lb
De-orbit	803 lb
Other	1,515 lb
Total	16,764 lb

Since the CER does not pretend to account for the cost of the de-orbit system, the 803 lb of de-orbit system weight must be subtracted out to arrive at the weight which the CER was designed to operate on. The result is 16,764 - 803 = 15,961 lb per tank set consisting of 6,954 lb of structure plus 9,007 lb of insulation and other material. Dividing by two to get the weights for a single tank gives 3,477 lb of structure and 4,504 lb of insulation and other for a total dry weight (less de-orbit system) of 7,981 lb per tank.

In Concept A, the basic structure of the tank is aluminum monocoque with a complexity factor of 0.6. Insulation and other material are assumed to have the same complexity factor as for the larger tanks (1.0). Taking the weighted average of these factors, the overall complexity factor for Concept A is

$$F_c = \frac{(0.6)(3477) + (1.0)(4504)}{7{,}981} = \frac{2086 + 4504}{7{,}981} = .826.$$

Therefore, the first-unit CER adjusted for the proper complexity factor for Concept A becomes

$$TFU = 5.95 \times 10^3 \times (W)^{.607} \times .826$$

$$TFU = 4.91 \times 10^3 \times (W)^{.607}.$$

For the weight of 7,981 lb,

$$TFU = 4.91 \times 10^3 \times (7981)^{.607}$$

$$TFU = 1.147 \times 10^6.$$

In the Lockheed cost model, total recurring costs for droptanks are arrived at by multiplying the first-unit cost by the appropriate learning factor and then adding an increment of 11.3 percent to account for systems support and management. When these factors plus a 10-percent fee are applied, the CER for total recurring cost becomes

$$C_R = (TFU)\ (1.113)(1.1)(F_L) = (1.224)(TFU)(F_L)$$

where F_L is the learning factor. This equation then should generate the CER estimate which corresponds to the detailed estimate of recurring cost for Concept A, less its de-orbit system.

Using the CER-derived value of TFU for the Concept A tanks, the CER estimate for Concept A recurring cost (in $ million) is

$$C_R = (1.224)(1.147)(L_F) = 1.404\ (F_L).$$

In previous cost estimates for the larger skin/stringer droptanks for the stage-and-one-half system, learning was postulated at 90 percent. For those tanks, this rate was somewhat validated by the close correspondence of CER estimates with the detailed estimates (see Appendix). However, for the Concept A droptank design, the detailed manufacturing estimates show that a learning rate of 92 percent is more accurate. At this rate, the learning factor for 900 tanks is 451. Therefore, using the CER, the total recurring cost for the Concept A tanks is

$$C_R = 1.404\ (451) = \$633 \text{ million.}$$

Thus, the CER estimate of $633 million for total recurring cost is the number to be tested against the detailed estimate for total recurring cost for Concept A, less the cost of the de-orbit system. The detailed estimate shows a total recurring cost of $650 million of which $15 million is contributed by the de-orbit system. The comparison then becomes $633 million as estimated by CER versus $635 million arrived at by detailed bottom-up estimate. The immediate implication is, that for the external hydrogen tanks, the existing CER is not only adequate but is exceptionally accurate. However, the match is so close as to be disconcerting. No reasonable cost analyst expects such precision out of CERs. Ruling out collusion and admitting some measure of coincidence, the two estimates seem to check each other. But to arrive at a really confidence-inspiring conclusion, it is necessary to check out the possibility that both the CER and the detailed estimate are wrong.

To investigate this area, other sources of cost estimates were examined. The resulting data are shown in Fig. 22-1. All data are normalized to give total recurring costs for the production of 900 tanks.

In the case of the Aerospace Corporation costs, the estimates were computed for the Concept A tank using the Aerospace CERs documented in Ref. 22-1. These costs include the droptank production costs as well as the Aerospace factors for spares, engineering support, management, and fee and, therefore, should represent total recurring cost. Two curves are shown for the Aerospace data: one which reflects the Aerospace recommended learning of 88 percent and one which represents the current Lockheed learning estimate of 92 percent.

Grumman weight and cost data were obtained from Ref. 22-2. McDonnell-Douglas data were taken from Ref. 22-3. The original Grumman cost data were based on a production quantity of 890 tanks and the McDonnell-Douglas data for 1000 tanks. Grumman postulates 90 percent learning and McDonnell-Douglas 85 percent. For comparative purposes, the cost data shown in Fig. 22-1 are based on an adjustment of these original data to show the costs for 900 units at these learning rates.

Figure 22-1 shows that the Aerospace CERs at 92 percent learning generate much higher costs than estimates from the other sources. However, there is a very close correlation between the Aerospace CER estimate and the Lockheed CER and detailed estimate at the Aerospace-recommended learning rate of 88 percent. The Grumman and McDonnell-Douglas estimates fall much below the

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CONCEPT A COST COMPARISON

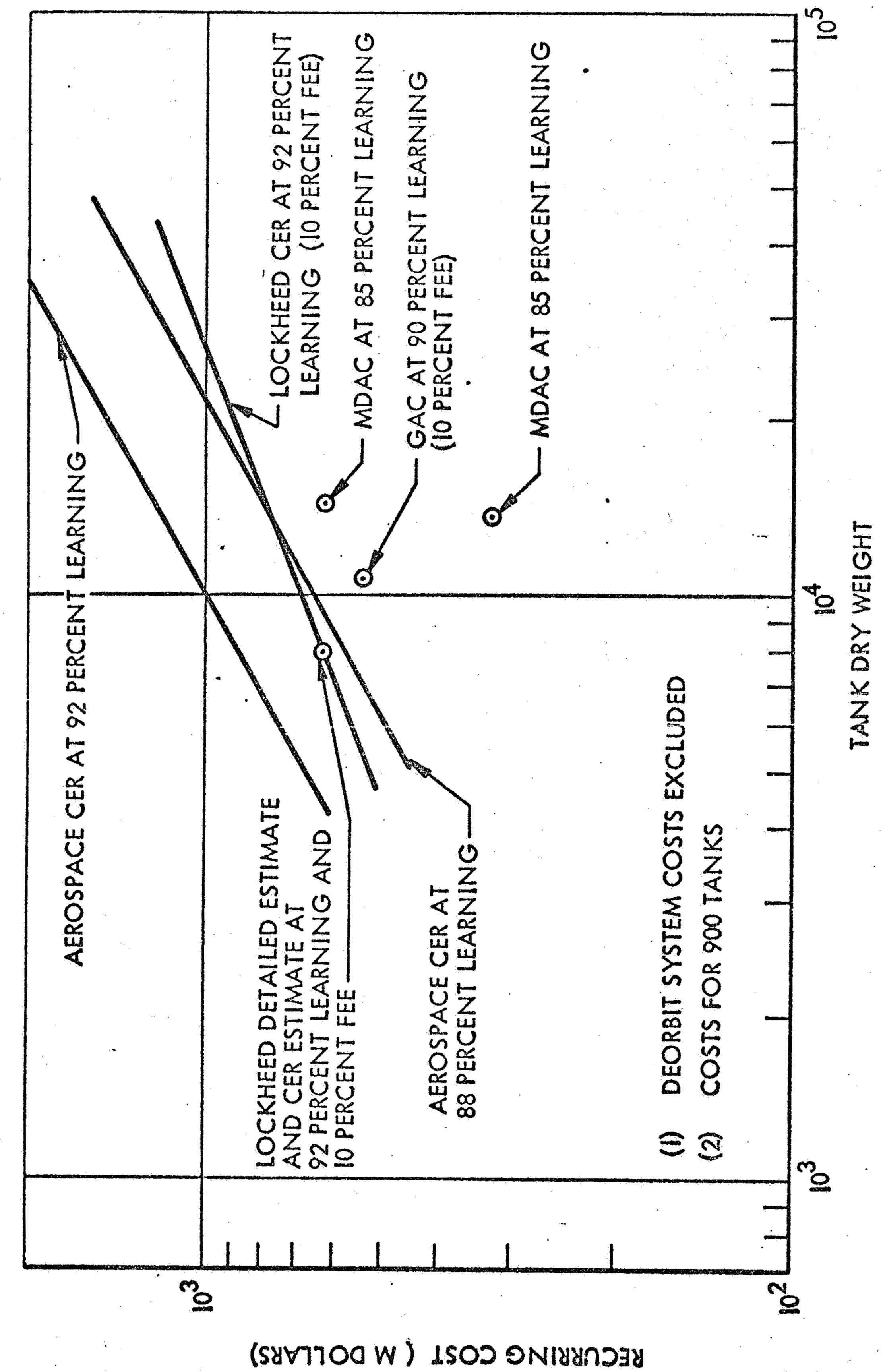

FIGURE 22-1

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FIG. 22-1

Lockheed and Aerospace estimates. However, the Grumman and McDonnell-Douglas cost data available to Lockheed were lacking in detail, and it is possible that they include only the production costs of the tanks and do not include other associated support costs.

One significant fact stands out in the data of Fig. 22-1. If an independent analyst were to compute Concept A recurring costs in two ways, one using the Lockheed parametric-costing methodology and the other using the Aerospace parametric-costing methodology, he would arrive at two estimates which would not exceed 10-percent variance throughout a weight range of 7,000 to 28,000 lb. Furthermore, he would have two parametric estimates which check within -0.3 percent (Lockheed) and -9.0 percent (Aerospace) with an in-depth, bottom-up estimate at the 8,000-lb weight. Therefore, the Lockheed recurring cost CERs are considered valid for the external tanks of Concept A, although for tanks in the weight range of concern and for this type of construction, it makes very little difference in total recurring cost whether the Lockheed CERs or Aerospace CERs are used to arrive at the estimate.

REFERENCES

22-1 Aerospace Corp.: STS Cost Methodology, Vol. I, Earth Orbit Shuttle Cost Methodology, dated August 1970 (Revised March 1971).

22-2 Grumman Aircraft Co.: Alternate Space Shuttle Contract Study 10th Monthly Review, dated April 28, 1971.

22-3 McDonnell-Douglas: External Tank Study, 3rd Status Report, dated May 25, 1971.

22.3 CONCEPT B TANKS

The total dry-weight distribution of Concept B, including contingency is,

Structure	6,700 lb
Insulation	7,492 lb
Deorbit	803 lb
Other	1,515 lb
Total	16,510 lb

Minus the deorbit system, this gives a weight per tank of 7,854 lb, consisting of 3,350 lb of structure and 4,504 lb of other. For this configuration, the complexity factor becomes

$$F_c = \frac{(0.6)(3,550) + (1.0)(4,504)}{7,854} = \frac{2,130 + 4,504}{7,854} = .845.$$

Using the CER for first-unit cost,

$$TFU = (5.95 \times 10^3)(7,854)^{.607} (.845)$$

$$TFU = (5.95 \times 10^3)(2.314 \times 10^2)(.845)$$

$$TFU = 1.164 \times 10^6$$

and using the same factors as Concept A for support, fee and learning, the recurring cost becomes

$$C_R = (1.224)(1.164)(451) = 643 \text{ \$ million.}$$

The corresponding number for Concept B by detailed estimate is $568 million ($583 million total minus $15 million for the de-orbit system).

In the case of Concept B, the detailed estimate is seen to come out as about 88 percent of the CER estimate (568/643). While this is certainly acceptable accuracy for CERs, it is not consistent with the CER estimate of Concept A, in that the Concept B tank with a lower structure weight and cheaper manufacturing process (weld-bond) should not cost more than Concept A. This discrepancy can only be explained by the fact that the CER is not sophisticated enough to take into account any differences in manufacturing processes. The detailed estimate, however, does take this difference into account. For lack of other data, the only avenue presently open to correct the CER to reflect costs for weld-bond tanks is to adjust it to agree with the only current detail estimate available for weld-bond tanks: the $568 million figure for Concept B.

The adjustment can be made by including a manufacturing complexity factor (F_{ms}) for weld-bond technique referenced to a manufacturing complexity factor of 1.0 for fusion welding and apply this new complexity factor to the structures weight of the tank.

The general form for computing overall complexity factor for the tank then becomes:

$$F_c = \frac{(F_{cms})\ (F_{ms})\ (W_s) + (F_{cmo})\ (F_{mo})\ (W_o)}{W_t}$$

where

F_{cms} = structures construction and material complexity factor

F_{ms} = structures manufacturing process complexity factor

W_s = structures weight

F_{cmo} = other construction and material complexity factor

F_{mo} = other manufacturing process complexity factory

W_o = weight of other than structures

W_t = total tank dry weight.

For Concept B, the factors for other-than-structure weights are 1.0 and a value of 0.64 for F_{ms} would make the CER estimate and detailed estimate agree.

That is, the overall complexity factor (F_c) becomes:

$$F_c = \frac{(0.64)(0.6)(3,550) + (1.0)(4,504)}{7,854} = \frac{1,363 \quad 4,504}{7,854} = .747$$

and $\quad TFU = (5.95 \times 10^3)(2.314 \times 10^2)(.747) = 1.029$ \$ million

and $\quad C_R = (1.224)(1.029)(451) = 568$ \$ million.

Therefore, for parametric estimating of weld-bond tanks in the weight range of 8,000 lb, it is recommended that a manufacturing complexity factor (F_m) of 0.64 be applied to the structures weight and combined with other complexity factors for material and type of construction to arrive at an overall complexity factor for computing recurring costs. Admittedly, this recommendation is based on openly fitting a CER to a point-design estimate. However, until the CER can be checked out against additional data on weld-bond tank estimates, it appears to be the best approach now in hand for parametric costing of these tanks.

22.4 CONCEPT C TANKS

The total dry-weight distribution of Concept C tanks is,

Structures	6,597 lb
Insulation	7,492 lb
Deorbit	803 lb
Other	1,515 lb
Total	16,407 lb

Minus the deorbit system, the weight per tank is 7,802 lb consisting of 3,298 lb of structure and 4,504 lb of other. In Concept C, the structures material is stainless steel. For this material, Lockheed data show a complexity factor of 1.0 for monocoque stainless steel construction.

The overall complexity factor (F_c) therefore becomes

$$F_c = \frac{(1.0)(3,298) + (1.0)(4,504)}{7,802} = 1.0.$$

Using the CER for first-unit cost,

$$TFU = (5.94 \times 10^3)(7,802)^{.607}(1.0)$$

$$TFU = (5.95 \times 10^2)(2.3045 \times 10^2)(1.0)$$

$$TFU = 1.37 \text{ \$ million}$$

and using the same factors as used in the other concepts for support, fee and learning, the recurring costs becomes,

$$C_R = (1.224)(1.37)(451) = 756 \text{ \$ million.}$$

The corresponding number by detailed estimate for Concept C is $640 million ($655 million total minus $15 million for the deorbit system).

In this case, the detailed estimate is about 85 percent of the CER estimate (640/756). Here again, the correlation is not bad but the difference is large enough to merit some further examination. The first area to come under suspicion is the complexity factor of 1.0 for stainless steel monocoque construction. This factor was derived from a Lockheed study performed in 1967, and is probably outdated. The Aerospace complexity factor for stainless monocoque construction is 0.8 (Ref. 22-1) and represents more recent data than the Lockheed study. If this complexity factor is used, the overall complexity factor is,

$$F_c = \frac{(0.8)(3,298) + (1.0)(4,504)}{7,802} = \frac{2,638 + 4,504}{7,802} = .915.$$

Using this new value for F_c,

$$TFU = (5.95 \times 10^3)(2.3045 \times 10^2)(.915)$$

$$TFU = 1.25 \text{ \$ million}$$

And $C_R = (1.224)(1.25)(451) = 690 \text{ \$ million.}$

This value of F_c brings the CER estimate within 7 percent of the detailed estimate.

Therefore, it is concluded that the existing CER will generate more accurate costs for stainless steel tanks if the materials and construction complexity factor for structures is changed to the Aerospace value of 0.8. This factor will be used in any subsequent evaluation of stainless steel monocoque tanks.

22.5 DDT&E CERs

The existing Lockheed CERs for droptank DDT&E (in $Millions) are:

$$C_{DDT\&E} = (C_D + C_{TH})(1 + F_{IM})$$

where,

C_D = development cost = .225 (Droptank Weight/Set)$^{.578}$

C_{TH} = test hardware cost = (TFU)(No. of Test Tanks)

F_{IM} = integration and management factor = .113.

These CERs do not include fee. When the 10-percent fee is added and the 7 test units of the detailed estimates are included, the combined CER becomes,

$$C_{DDT\&E} = .275(\text{Weight/Set})^{.578} + 8.57\ (\text{TFU}) \text{ in \$ millions.}$$

Using the TFU costs as derived by the updated CERs described previously, the following estimates are arrived at for total DDT&E costs:

Concept A	Concept B	Concept C
$83M	$80M	$85M

These correspond to the sums of nonrecurring DDT&E and nonrecurring production costs as arrived at by the detailed estimate as:

Concept A	Concept B	Concept C
\$114M	\$121M	\$127M

It is seen that the CERs generate much lower costs than the detailed estimates in the 16,000-lb range of tank weights. However, the same CERs have been shown to generate good DDT&E costs in the range of 119,000 lb. Assuming that the CER costs for TFU are correct, this suggests that the slope of the cost-weight curve which generates the development cost (C_D) is wrong.

The detailed estimates at the low weight range provide the means for correcting the cost-weight curve. When the CER for development cost (C_D) is adjusted to fit the detailed estimate for stage-and-one-half tanks at 119,000 lb and the detailed estimates for the current tanks which are in the neighborhood of 16,500 lb, the following CER results:

$$C_D = 4.54\ (\text{Weight/Set})^{.312}.$$

By this CER, the following estimates for DDT&E costs are achieved:

Concept A	Concept B	Concept C
\$125M	\$124M	\$126M

The correlation between CER estimates and detailed estimates becomes much better when the corrected CER for droptank development costs is used. Also as an outside check, the new CER agrees very closely with the Aerospace CER for droptank development, excluding tooling. The corresponding Aerospace CER is

$$C_D = (F)(2.72)(\text{Weight})^{.347}$$

where F is a development complexity factor which can range from 1.0 to 2.4 for new development.

Therefore, it is considered that the corrected CER for droptank development be used in future parametric-cost evaluations of droptanks.

Total Cost Comparisons

Using the adjusted CERs, the following estimates for Concepts A, B, and C (less deorbit system) result:

	CONCEPT A		CONCEPT B		CONCEPT C	
	Detailed	CER	Detailed	CER	Detailed	CER
Nonrecurring	(114)	(125)	(121)	(124)	(127)	(126)
DDT&E	54		58		58	
Production	60		63		69	
Recurring	(635)	(633)	(568)	(568)	(640)	(690)
Total	749	758	689	692	767	816

(Costs in $ millions)

22.6 SYSTEM COST TRADES

A summation of droptank costs from the detailed estimates and system weights for the three concepts (using Concept A as a reference baseline) including deorbit system is as follows:

	CONCEPT A	CONCEPT B	CONCEPT C
Total Cost ($M)	764	704	782
Δ Cost (#M)	0	-60	+18
Weight (lb)	16,764	16,510	16,407
Δ Weight (lb)	0	-254	-357

For a case where droptank propellant capacity and orbiter weight are considered fixed, any change in droptank dry weight must be counteracted by a change in booster weight (structure and propellants) to maintain performance constant.

When these weight sensitivities are translated into cost sensitivities using Lockheed CERs, the effect on booster cost are found to be $8,800/lb ($8,000 + 10% fee) of droptank system dry weight. This is the total program cost impact on the booster alone over a 10-year, 445-flight program. It does not include the direct cost of the one-pound change on the droptanks themselves since this is assumed to be accounted for in the above estimates of droptanks cost.

When this effect on the booster is taken into account, Concept B is seen to result in an additional cost savings of $2.2 million ($8,800 x 254 lb) over Concept A to give a total cost savings of $62.2 million. In the same manner, the lower weight of Concept C results in an additional savings of $3.1 million ($8,800 x 357 lb) to give a net cost increase over Concept A of $14.9 million ($18 million - $3.1 million). While these effects have no significant impact on the evaluation of the three concepts investigated, they should be kept in mind in the evaluation of other concepts with different cost differentials and weight and cost sensitivities.

22.7 FUSION-WELD DESIGN COST COMPARISON

Figures 22-2 and 22-3 show comparisons of the Lockheed-derived data on the fusion-weld design (Concept A) with corresponding data from other sources. GAC data were extracted from Reference 22-2 and MDAC data from Reference 22-3. The GAC estimate is based on a quantity of 890 tanks at 90-percent learning. A 10-percent fee has been added to the original GAC estimate to make it consistent with the other data. The MDAC estimate is for 1,000 tanks at 85-percent learning and includes an unspecified fee. All Lockheed data points are for 900 tanks and include 10-percent fee.

Figure 22-2 shows the various estimates as a function of weight. The larger stage-and-one-half tank is seen to fall above the CER trend line for monocoque structure, a result which is understandable by virtue of the fact that the

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FUSION-WELD DESIGN COST COMPARISON
COST VERSUS WEIGHT

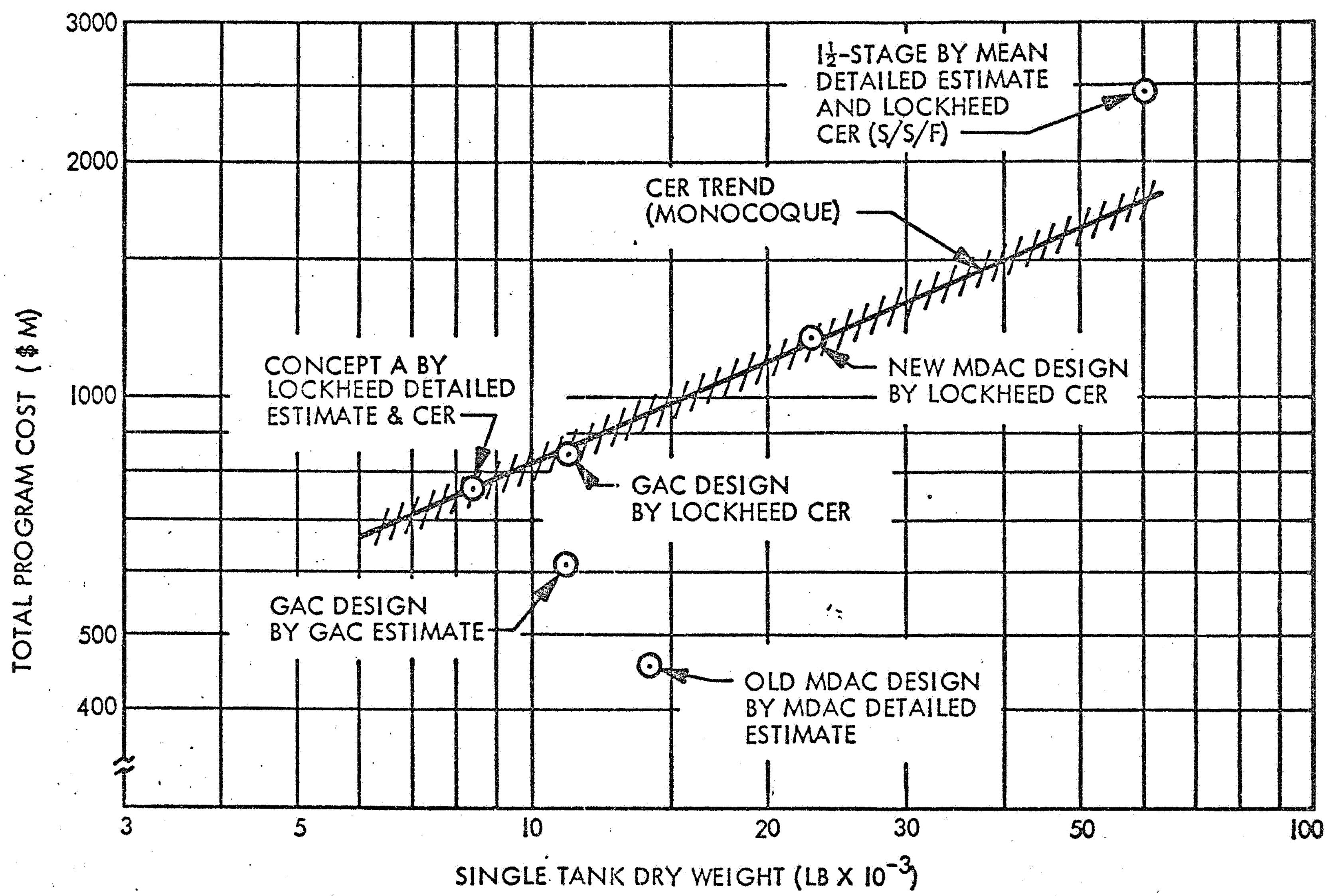

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Fig. 22-2

Fig. 22-2

FUSION-WELD DESIGNS COST COMPARISON
COST VERSUS VOLUME

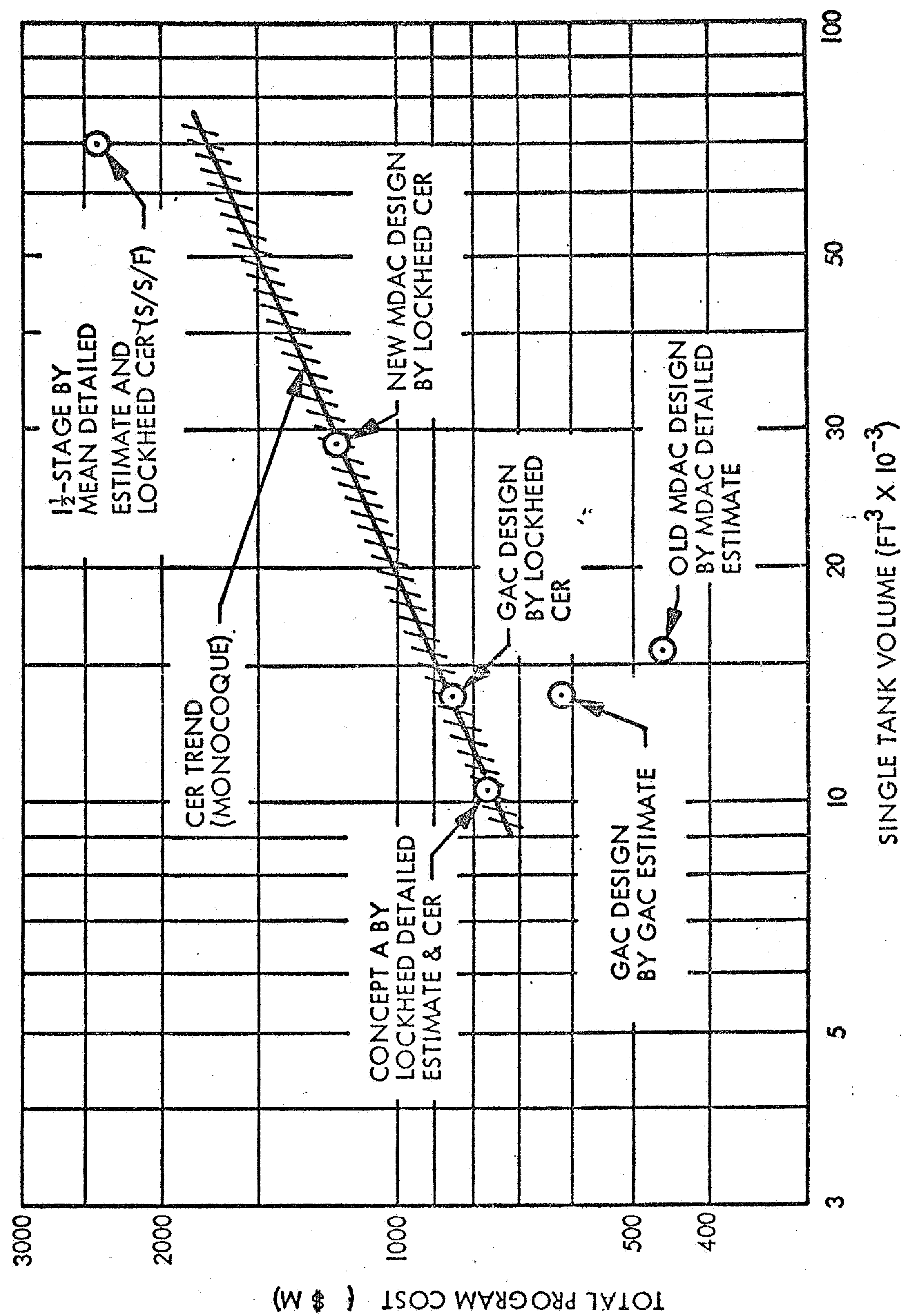

Fig. 22-3

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Fig. 22-3

stage-and-one-half tank is of skin/stringer/frame construction. Figure 22-3 shows the same cost estimates as a function of tank volume. The close fit of the estimates to the trend line indicates that, for single propellant tanks without internal bulkheads or connecting sections, CERs based on volume would yield consistent results.

Section 23

COST SENSITIVITY TO PROGRAM SIZE

All previous cost estimates were based on the quantity of tanks required to support a 450-flight operational program. In order to assess the impact on cost of varying the size of the program, these estimates were extended to estimate the tank costs for programs having more or less flights than the nominal traffic model.

For this purpose, the detailed estimates for recurring costs for all three concepts were reflected back along a 92-percent learning curve to arrive at a Theoretical First Unit (TFU) Cost for each concept. These were then projected at 92-percent learning to compute new recurring costs for various program sizes. The nonrecurring costs from the detailed estimates were then added to arrive at total tank costs for each program size.

Figure 23-1 shows total tank costs as a function of the number of flights in the program. At 1000 flights, total costs are $1,426 million for Concept A, $1,298 million for Concept B and $1,449 million for Concept C. Figure 23-2 shows the average total tank cost per flight for various sizes of flight programs.

Fig. 23-1

TANK COST VS. NUMBER OF FLIGHTS

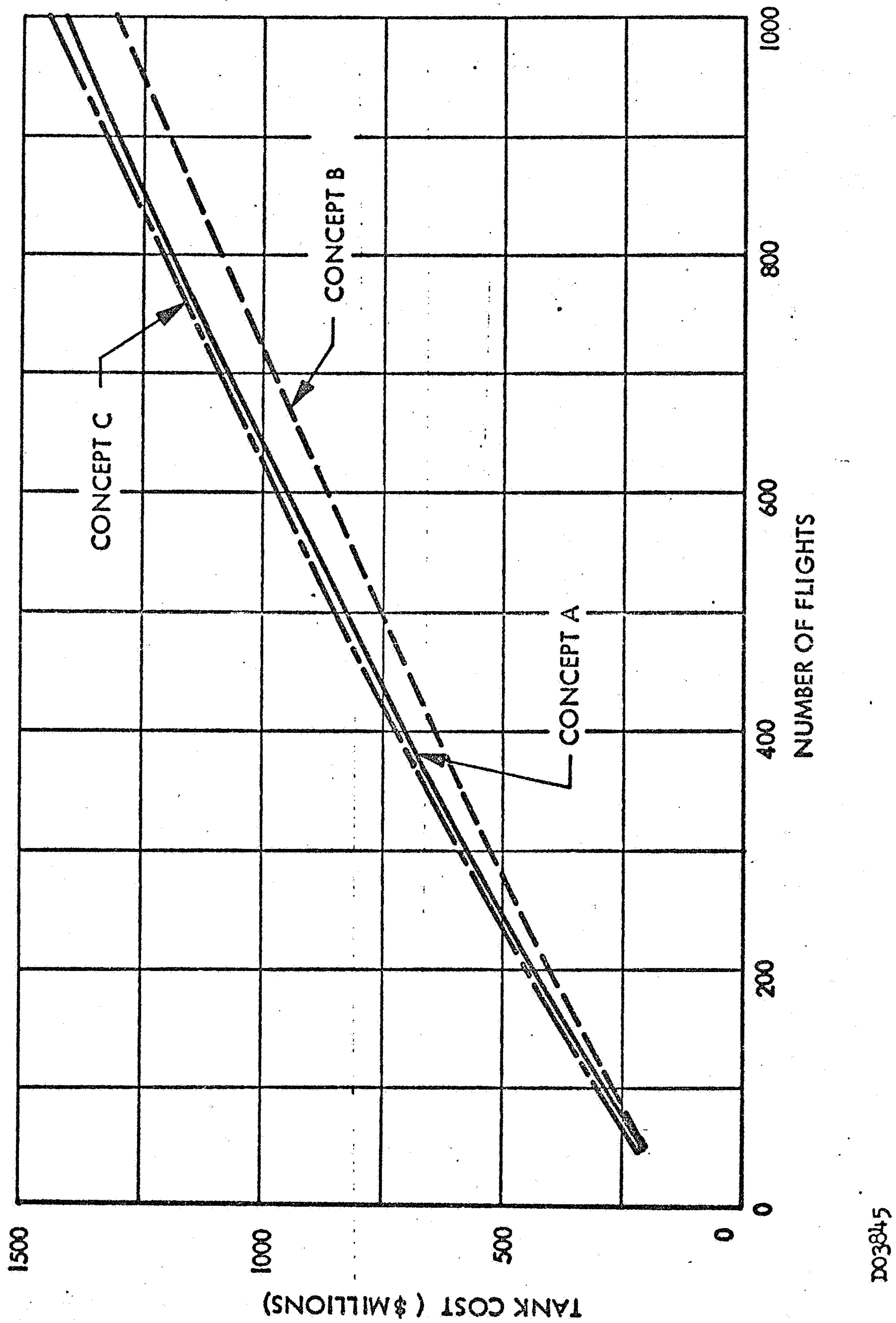

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Fig. 23-1

Fig. 23-2

TOTAL TANK COST/FLIGHT VS. NUMBER OF FLIGHTS

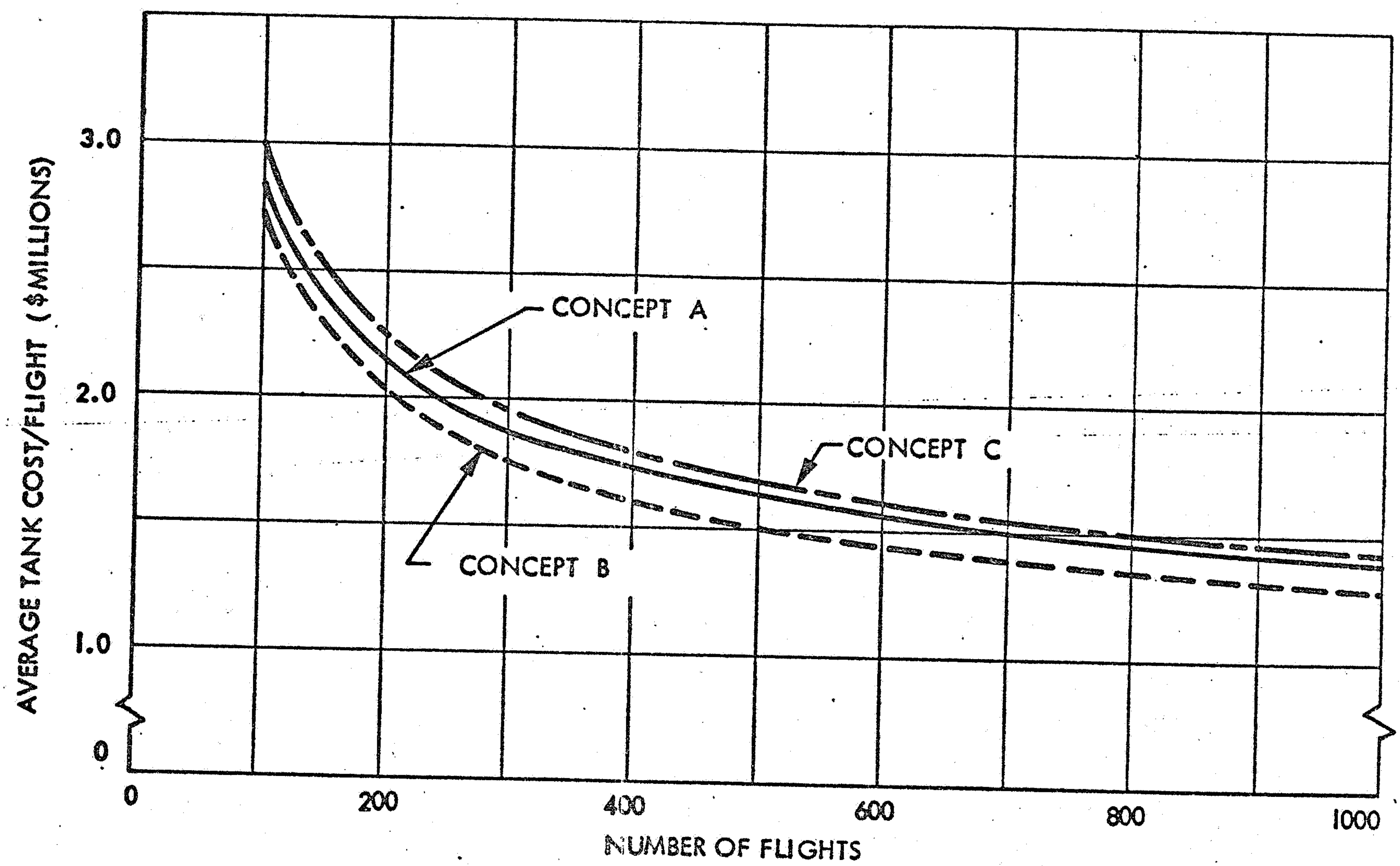

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Fig. 23-2